Report of
Defense Science Board Task Force
on

DEFENSE SEMICONDUCTOR DEPENDENCY

February 1987

Office of the
Under Secretary of Defense
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DEFENSE SCIENCE BOARD

9 FEB 1987

MEMORANDUM FOR THE SECRETARY OF DEFENSE

THROUGH: UNDER SECRETARY OF DEFENSE FOR ACQUISITION

SUBJECT: Report of the Defense Science Board Task Force on "Semiconductor Dependency" -- ACTION MEMORANDUM

I am pleased to forward the final report of the Defense Science Board (DSB) Task Force on "Semiconductor Dependency," prepared under the chairmanship of Mr. Norman R. Augustine. The study addresses the impact of dependency of the U.S. military on foreign sources for semiconductor devices. All of our advanced military systems make use of such devices. Our remarkable technology achievements in semiconductor devices account, in large measure, for the superior performance of all our advanced systems. The report concludes that, while our current dependency on foreign sources is modest today, semiconductor manufacturing trends indicate that we will become highly dependent in the future if immediate actions are not taken. The most significant finding of the Task Force is that U.S. technology leadership in this critical area is rapidly eroding and that this has serious implications for the nation's economy and immediate and predictable consequences for the Defense Department. The report further concludes that action must be taken to:

a. Retain a domestic strategic production base.

b. Maintain a strong base of expertise in the technologies of device and circuit design, fabrication, materials refinement and preparation, and production equipment.

Specific recommendations are made by the Task Force to address these critical areas. The recommendations call for cooperative government, industry, and university actions. Because of the time-sensitive nature of this problem, immediate action is recommended.

In summary, this DSB report focuses on a critical national problem that at some time in the future may be looked upon in retrospect as a turning point in the history of our nation. The implications of the loss of semiconductor technology and manufacturing expertise, for our country in general and our national security in particular, are awesome indeed.

The report represents the unanimous views of the Task Force members. In addition, some of the members concluded that a "Buy American" policy in semiconductors would also have an important and useful impact; others disagreed. I believe the issue warrants further exploration and have included it in the attached memorandum for your consideration.

Regardless of what caused our current predicament, the resulting problem is critical not only to DoD but to the nation. The DoD cannot solve the problem alone but can take some important actions itself, and take the lead in pushing for a national effort.

I strongly recommend that you read Mr. Augustine's transmittal letter, review the Executive Summary, and sign the attached memorandum. I also urge you to raise this issue at the highest levels of our government as one of critical national importance.

Charles A. Fowler

Charles A. Fowler

Attachments
1. Memorandum
2. Transmittal Letter
3. Executive Summary

OFFICE OF THE SECRETARY OF DEFENSE
WASHINGTON, D.C. 20301

DEFENSE SCIENCE
BOARD

December 31, 1986

Mr. Charles A. Fowler
Chairman
Defense Science Board
Office of the Secretary of Defense
The Pentagon
Washington, D.C. 20301-3140

Dear Mr. Fowler: Bob

Submitted herewith is the final report of the Defense Science Board Task Force on Semiconductor Dependency. The report is the result of an approximately 10-month effort during which the Task Force interrogated some 50 expert witnesses, surveyed the existing literature on the subject, and solicited via the Federal Register comments from all interested parties.

The Task Force concludes that procurement by the Department of Defense is a relatively insignificant factor to the semiconductor industry; but, in contrast, the existence of a healthy U.S. semiconductor industry is critical to the national defense. Because of this asymmetry, the Task Force believes that it is imperative for the Department of Defense to take action to assure the long-term viability of a U.S. semiconductor industry which can at least meet critical defense needs. Semiconductors today represent the most highly leveraged and most ubiquitous element for assuring the technological superiority of the United States' military forces.

It is widely recognized that the manufacturing capacity of the U.S. semiconductor industry is being lost to foreign competitors, principally Japan. It is less widely recognized, but of even greater long-term concern, that technological leadership is also being lost.

It would be relatively easy to blame these ominous happenings on various forms of inappropriate behavior of foreign competitors. This would, however, be a gross oversimplification. For a multitude of reasons, the U.S. has not positioned itself to compete effectively in the world semiconductor market. The consequences of this fact are now being suffered.

Although the implications of these trends on the nation's economy as it enters the information age are serious indeed, the consequences for the Department of Defense are more immediate and predictable. Certain actions can nonetheless be taken which may enable the U.S. semiconductor industry to re-establish itself as a viable world competitor and a source of state-of-the-art semiconductors for defense needs. The most important of these actions is for the Department of Defense to encourage and actively support with contract funding (approximately $200M per year) the establishment of a U.S. Semiconductor Manufacturing Institute formed as a consortium of U.S. manufacturers. The purpose of this private consortium is to perform generic manufacturing process development for very advanced semiconductor devices and to sponsor equipment and materials research and development which will benefit the U.S. semiconductor industry's contributions to our economy in general and national defense in particular. The fact that this investment by the government does benefit the commercial competitiveness of U.S. merchant semiconductor firms would be an unfortunate basis for withholding Defense Department support of these recommendations which are viewed as critical to national defense. It is simply no longer possible for individual U.S. semiconductor firms to compete independently against world-class combinations of foreign industrial, governmental and academic institutions which have benefited from more benign financial and structural environments abroad.

The individual members of the Defense Science Board Task Force consider the nation's growing dependency on foreign sources for vital semiconductor hardware and technology to be among the most serious matters they have had the occasion to address in their various associations with the Department of Defense. Further, there exists a considerable time urgency because of the rate at which market position and technological capability are deteriorating in this rapidly changing field.

The members of the Task Force stand ready to assist in the implementation of the recommendations.

Sincerely,

Norm

Norman R. Augustine

/ljc
Enclosure

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EXECUTIVE SUMMARY

SECTION I

EXECUTIVE SUMMARY

1.0 INTRODUCTION

U.S. Defense strategy relies upon technologically superior weapons to overcome the numerical advantage of our adversaries. Our capability to field technologically superior weapons may soon, however, be dangerously diminished.

The superiority of U.S. defense systems of all types is directly dependent upon superior electronics, a force multiplier which not only enhances the performance of the weapons themselves, but also maximizes the efficiency of their application through sophisticated intelligence and command and control systems. Electronics technology is therefore the foundation upon which much of our defense strategy and capabilities are built. The United States has historically been the technological leader in electronics. However, superiority in the application of innovation no longer exists and the relative stature of our technology base in this area is steadily deteriorating.

As evidenced by market share and the perception of the technical and financial communities, the United States' semiconductor device and related "upstream" industries, such as those that supply silicon materials or processing equipment, are losing the commercial and technical leadership they have historically held in important aspects of process technology and manufacturing, as well as product design and innovation. The U.S. semiconductor industry may very soon, in fact, be competitive only in very small, "specialty" segments of the overall market. This situation has arisen partly because of loss, in some areas, of technological leadership, resulting in an inability to compete with high-quality products in commodity markets.

The following reasoning, reflecting the considered judgments of the Task Force, suggests that a direct threat to the technological superiority deemed essential to U.S. defense systems exists:

- U.S. military forces depend heavily on <u>technological superiority to win</u>.
- <u>Electronics</u> is the technology that can be leveraged most highly.
- <u>Semiconductors</u> are the key to leadership in electronics.
- <u>Competitive</u>, <u>high-volume production</u> is the key to leadership in semiconductors.
- High-volume production is supported by the <u>commercial</u> market.

- Leadership in commercial volume production is being lost by the U.S. semiconductor industry.

- Semiconductor technology leadership, which in this field is closely coupled to manufacturing leadership, will soon reside abroad.

- U.S. Defense will soon depend on foreign sources for state-of-the-art technology in semiconductors. The Task Force views this as an unacceptable situation.

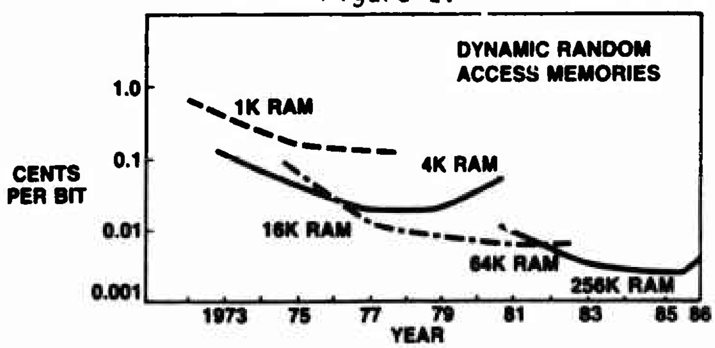
This report amplifies the above argument, assesses the current status of the U.S. semiconductor industry, and identifies causes of its loss of technological leadership. To minimize the harmful effects on national security that are threatened by this loss, a joint Department of Defense/Industry initiative, comprising research, educational, production, and administrative elements to address the most pressing needs in semiconductor technology, is proposed.

2.0 FINDINGS

2.1 The extent of the dependence of defense systems that are now in the field on foreign semiconductors is difficult to determine, but evidence indicates that in the newest systems about to be deployed a significant fraction of chips used -- up to several tens of percent -- are either entirely made, or packaged and tested, abroad. If steps are not now taken to assure the availability of domestic sources or stockpiles, or both, the U.S. could be denied timely access to these militarily critical devices in wartime or, as will be shown, forced to rely upon technologically and operationally inferior alternatives.

2.2 Dynamic random access memories (DRAMs) are the most challenging semiconductor chips to manufacture competitively, and their development establishes the pace for progress in semiconductor technology. It is this chip which largely establishes the cost trends for the semiconductor industry, and major reductions in price have been achieved over the years as displayed in the figure.

Figure 1.



SOURCE: BUREAU OF INDUSTRIAL ECONOMICS

With the exception of some production by captive manufacturers, DRAMs are now being produced primarily in Japan and, to a limited extent, in Korea. Many important kinds of devices, such as other types of memory, microprocessors, signal processors, and gate arrays, build upon DRAM technology, and the focus of their manufacture, is very likely to follow DRAMs. As the production base moves abroad, it is being accompanied by the related upstream supply industries, which include the semiconductor materials and manufacturing equipment industries. Downstream industries have also moved offshore at an accelerating pace. This group, including telecommunications and computers, has been estimated to represent a $500 billion per year worldwide industry by the early 1990's and a $1 trillion industry in the year 2,000.

2.3 The United States semiconductor industry arguably retains superiority in the <u>design</u> of integrated circuits, although the gap in this advantage is closing; and in the production of high-technology specialty chips which can be profitably sold in low volume.

2.4 In the absence of a domestic mass-production revenue base needed to preserve a viable domestic production equipment industry, the specialty producers themselves may become dependent on foreign suppliers for their materials, equipment and fabrication technology, and would then be at a disadvantage when under competitive assault by firms controlling the access to those resources.

2.5 Substantial technological and production resources can be found within the captive segment of the U.S. semiconductor industry (firms which embed their semiconductor production in their own end-products), especially at AT&T and IBM. These firms depend, however, on the same materials and equipment industries used by the merchant segment, and the captive firms' product focus, determined by their internal device needs, may match only partially DoD needs. They have not been significant suppliers of devices to the defense prime contractor community. Further, as production and design capabilities move increasingly overseas, even these organizations may become dependent on overseas suppliers.

2.6 Acquisition of specific devices or materials from foreign sources for defense applications is not a critical problem as long as the U.S. has the knowledge and resources to substitute domestic sources in a timely fashion should the supply of foreign products and technology be interrupted. However, this substitution is possible only if it can in fact be accomplished within the time available and does not impoverish U.S. capabilities in other important areas.

2.7 Even more critical is the possible movement of electronic device and system capabilities to overseas locations from which the Soviet Union can readily access the technology. In that case, the U.S. could lose the considerable margin of advantage it holds over the U.S.S.R. in this critical area of technology -- and upon which it relies to offset quantitative military disadvantages.

2.8 In light of the conclusions above, continued availability to the Department of Defense of the most technologically advanced products will be dependent on the maintenance of a domestic leading edge technology development and production base capable of timely supply of defense needs. This availability is by no means assured. Therefore, action must be taken to retain an adequate domestic production base to meet defense needs.

2.9 In order to retain needed infrastructure for such "downstream" industries as those of computers and telecommunications, which supply DoD needs, action must be taken to maintain a strong base of expertise in the technologies of device and circuit design, fabrication, materials refinement and preparation, and production equipment.

2.10 While semiconductor technology is essential to modern defense, DoD accounts for less than ten per cent of the world semiconductor market by sales dollars and about three percent by quantity. This asymmetry between the criticality of Department of Defense needs and the relatively small importance of DoD business to the industry implies that specific government action is justified (and needed) to support the government's own requirements.

2.11 The Department of Defense currently requires extensive qualification and testing of the semiconductor devices it procures and pays a substantial premium for the procedures and accompanying documentation. By procuring the highest quality parts commercially available for selected applications, as opposed to imposing militarized hardware specifications, savings could be selectively derived. The use of this approach must obviously be tailored to the specific application including consideration of its operating environment.

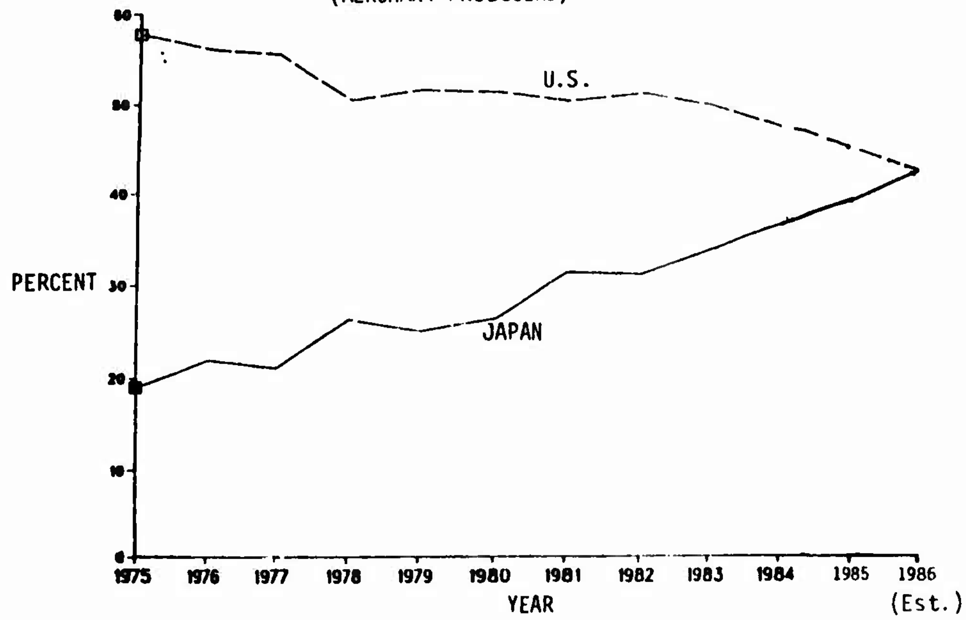
3.0 CURRENT STATUS OF THE INDUSTRY AND FUTURE TRENDS

3.1 Market Shares

Figure 2 summarizes market-share data for the worldwide merchant semiconductor industry. Data are included for DRAMs, the most important commodity product, as well as for other semiconductor devices. Since almost all Japanese semiconductor producers are vertically integrated firms which in addition sell devices to other companies, while few of the U.S. vertically integrated firms sell any (or many) devices to others, data is included only for merchant producers. This measure is of most relevance to the Department of Defense's circumstance. (A "merchant" supplier is one which, as opposed to a captive producer, sells integrated circuits for incorporation into the end-products of others.)

Figure 2.

JAPAN-US: SHARE OF WORLDWIDE INTEGRATED CIRCUIT SHIPMENTS
(MERCHANT PRODUCERS)



3.1.1 Status and Trends

The U.S. share of the worldwide merchant semiconductor market has declined steadily over the past decade from nearly 60 percent in 1975 to less than 50 percent in 1985. Estimates for 1986 indicate a further decline to below 45 percent. Japan's share of the market over the same period has increased from 20 percent in 1975 to 40 percent in 1985 and is estimated at slightly over 45 percent in 1986, thereby surpassing the U.S. share for the first time. If captive as well as merchant producers are included in the data, the U.S. share has declined from 67 percent in 1975 to 50 percent in 1986, while Japan's share has grown from 25 percent to 39 percent. In the critical area of DRAM production, the U.S. share has declined from near 100 percent to less than 5 percent for merchant producers. The rise in Japanese market share has been at the expense of both European producers and American merchant (i.e., semiconductor-chip-only) producers. Again, it is this latter group which supports most of the Department of Defense's needs.

The U.S. merchant producers' share of the worldwide semiconductor market has decreased by almost twenty per cent over the last four years. The loss to American captives is primarily in non-commodity and proprietary products, while that to the Japanese is in the technologically pivotal commodity memory market and other growing commodity products. The threatened loss of the entire commodity semiconductor business by the U.S. merchant producers has put these companies at significant risk. The seriousness of this risk is evidenced by the fact that, as noted above, in slightly over a decade the U.S. share of the most advanced generation of DRAM has fallen from near 100 percent to less than 5 percent.

3.1.2 Reasons for Market-Share Trends

The loss in market share of U.S. firms is in fact attributable principally to their loss of the high-volume DRAM business. American merchant producers are no longer able to develop and produce in the U.S. low-price, reliable DRAMs in a time scale necessary to achieve significant market penetration. Although actions by Japan, leading to early government support of semiconductor development and allegedly explicit and implicit trade barriers, including the use of restrictive exchanges of products among individual Japanese firms and "dumping," have contributed to the growth of the industry in that country, changes in these policies by themselves will not solve the problems that beset the U.S. semiconductor industry.

<u>The major reason for the relative inadequacy of technology development in the U.S. vis-a-vis that in Japan has been the difference in the industrial practices and structure of the two countries</u>. Japanese companies have invested a larger fraction of sales in plant and equipment (approximately 35 percent vs. 20 percent) than the U.S. merchant companies every year from 1970 through 1985. Japanese industry has also, in percentage terms, consistently outspent U.S. industry in Research and Development (approximately 13 percent vs. 10 percent). In the U.S., as profits disappeared, so did research and development. In contrast, in the most recent semiconductor recession, Japanese firms increased research and development expenditures even at a time when it elected to cut back somewhat on capital improvements. It is important to note that the Japanese R&D investment has primarily been in technology development with a long-term payoff, while that which American firms call "R&D" (for tax purposes) is usually the design and development of new products intended to be placed on the market as soon as possible. Thus the "R&D" investment of the U.S. merchant firms may well provide little direct basis for long-term growth.

A major reason underlying the success of the Japanese semiconductor effort is their effective combining of both competitive and cooperative R&D activities. For the development of basic technology, cooperative arrangements which avoid duplication are often employed, many of them under the coordinating leadership of Ministry of International Trade and Industry (MITI) or Nippon Telephone and Telegraph (NTT). In the application of the resulting technology to products, the companies compete fiercely. Even within a single company, competing parallel efforts are supported and the winning solution adopted. In contrast, in the U.S. less funding is available, and cooperative programs are only now beginning to appear.

Differences between U.S. and Japanese economic practices which contribute to differences in investment practices include (among many other factors ranging from the cost of labor to currency exchange rate):

1. Industry Structure
2. Cost of Capital
3. Access to Capital
4. Necessary profitability levels

1. The semiconductor <u>industry structure</u> in Japan is fundamentally different from that in the U.S. Virtually all of the Japanese firms that sell semiconductor products are considerably larger than the U.S. merchant producers and are, besides, both vertically integrated

and horizontally diversified. It can be argued that vertical integration provides a stimulus for advanced product development as well as a justification for the support of internal manufacturing capability. The major Japanese companies, such as NEC, Hitachi, and Toshiba, can consume up to twenty percent of their own production, which contributes to internal economies of scale, guarantees a threshold use of facilities, and provides a testing ground for new designs and concepts. Importantly, it also provides a degree of staying power in periods of downturn in a given market sector. The U.S. captive firms do not have an equivalent in the U.S. since they do not sell their integrated circuits to other systems manufacturers and represent a much narrower spectrum of technology than the Japanese merchant/captive suppliers as a group.

2. Cost of capital in the U.S. was considerably higher than in Japan for a period of several years in the early 1980's. Indirect financial influences, including management readiness to borrow for capital expansion and R&D, stockholder perception of financial soundness, profitability required to meet interest payments, etc., have had important impacts.

3. Access to Capital does not seem to have been a dominant concern for the managers of the U.S. merchant semiconductor firms, at least in their best years; for example, in the profitable years of 1983 and 1984 many merchant semiconductor producers retired considerable amounts of their long-term debt.

4. The profitability as a proportion of sales of U.S. firms generally must be higher than that of Japanese firms if they are to survive because the U.S. firms must compete for capital in the open marketplace. Naturally, having a higher percentage of sales available for R&D and capital expansion, as is the case for Japanese producers, can lead to competitive advantages in the capital and R&D-intensive semiconductor industry. Evidence that Japanese R&D expenditures are primarily in the "long-term reward" category lies in the rapid development of processing technology pursued in that country at the expense of near-term new product designs.

In the large Japanese companies, diversity allows capital expansion and R&D to proceed even in periods of recession. Within a diversified company the non-semiconductor businesses may cross-subsidize the semiconductor businesses. The capital markets in the U.S. perform, to some extent, this supporting role since in bad times money may be borrowed. The Japanese vs. American practice in accounting for repayment of such internal vs. external loans, and the effect of recourse to capital markets on company ownership and control (leading to a reluctance on the part of U.S. merchant company managers to seek outside funding even if they were able to do so) are also important in understanding the role of size and diversity in the growth of Japanese semiconductor producers.

When technology moves as fast as it does in the semiconductor industry, the timeliness of introduction of a new technology is important in establishing and maintaining a competitive edge. A six-month lag can be decisive in a key market such as DRAM production. Japanese firms have reached a point where they now are able and willing to introduce high-quality, reliable, device technology into the market faster than can U.S. firms. This can have important implications as vertically integrated Japanese firms with leading technology enter the market for end-use products which depend for their uniqueness on the availability of the most advanced semiconductors. The computer industry is but one example of such a sector.

3.2 Technology Status and Trends

Table I summarizes the current technical position of the U.S. semiconductor industry relative to that of Japan, as well as predicted changes in this position based upon present trends. The U.S. appears to be "behind" Japan in more areas than those in which it is ahead, and is not gaining ground in technologies important to the future. U.S. producers are increasingly becoming incapable of producing the highest-technology products with sufficient quality in high volumes and with the timeliness required to achieve profitability by American capital-market standards.

Table 1.

STATUS AND TRENDS OF U.S. SEMICONDUCTOR TECHNOLOGY RELATIVE TO JAPAN

	JAPAN LEAD	U.S.-JAPAN PARITY	U.S. LEAD
Silicon Products			
DRAMs	◀		
SRAMs	◀		
EPROMs		●	
Microprocessors			◀
Custom, Semicustom Logic			◀
Bipolar	◀		
Nonsilicon Products			
Memory	◀		
Logic	◀		
Linear			●
Optoelectronics	◀		
Heterostructures	◀		
Materials			
Silicon	◀		
Gallium Arsenide	◀		
Processing Equipment			
Optical Lithography		◀	
E-beam Lithography			◀
X-ray Lithography		◀	
Ion Implantation Technology			
Chemical Vapor Deposition		●	
Deposition, Diffusion, Other		●	
Energy-Assisted Processing	◀		
Assembly		●	
Packaging	◀		
Test	◀		
CAE		●	
CAM		◀	

▶ U.S. Position Improving
● U.S. Position Maintaining
◀ U.S. Position Declining

Source: Interagency Working Group on Semiconductor Technology

3.2.1 Technology Summaries

Japan exhibits a clear and increasing lead in most silicon product technologies, with the exception of design-intensive custom logic and microprocessors. In the latter products, and particularly in 32-bit microprocessors, however, the U.S. lead is being reduced by Japanese collaboration gains in design and, to a lesser extent, software expertise. In addition to pure technology levels, real as well as perceived differences in quality between U.S. and Japanese products have, since a comparison by a U.S. firm of the reliability of DRAMs in the late 1970's, accounted for differences in sales. Japanese firms have traditionally devoted greater priority to product quality than U.S. firms and this has had a substantive impact in the marketplace. Continuous efforts by U.S. merchants to improve their products since the initial study have produced considerable improvement in DRAMs, but equivocal results in other products.

In nonsilicon products, such as compound semiconductor optoelectronics and fast digital technologies, and particularly in optoelectronic integrated circuits, the U.S. also trails Japan. The U.S. currently maintains a lead in linear compound semiconductor IC technology, largely because of military interest in fast and radiation-hard circuits for satellite and radar applications.

In most processing equipment, much of which may be used for either silicon or compound semiconductor production, U.S. technology is on a general level with Japan's, although Japan is pulling ahead in key areas as a result of large technology development programs applicable to device manufacture. The relative technological position of the U.S. and Japan, according to one study, are summarized in Table 1.

3.2.2 Reasons for Technology Trends

Much of the difference between the U.S. and Japan in current and predicted technology attainments may be explained by economic factors that affect the relative investment levels in the two countries. However, cultural differences, which are reflected in employment and engineering practices, account for a part of the relative success of Japan not only in this, but in other high-technology areas. In the U.S., these differences are apparent in:

1. Lower productivity
2. Demand for a higher wage base
3. Occasional lower standards of quality
4. An adversarial relationship among management, labor, academia and government
5. Neglect of the technical manpower base

Further, engineering practice in Japan differs considerably from that in the U.S. and is related to the length and consistency of employment of Japanese engineers. In Japan, many specific engineering techniques are learned in the company, where engineers can acquire a deep, but narrow, expertise. Company identification brings about an emphasis on quality of product, and engineers' experience is efficiently utilized through long-term employment. In addition, the perceived importance of mass production at all stages of the research, development, and design processes ensures efficient production of even the newest devices. Ironically, U.S. government procurement policies which have placed major emphasis on reducing cost have had the unintended effect of further stimulating U.S. suppliers to procure abroad.

3.3 Effects on Upstream Industries

Upstream industries are those which supply products to semiconductor device manufacturers, including manufacturers of high-purity chemicals, and silicon wafer suppliers. Perhaps the most important of the upstream industries is that which supplies semiconductor manufacturing equipment (SME). Any commodity semiconductor manufacturer must utilize the latest SME in order to remain competitive.

The U.S. has been losing market share in SME markets even more rapidly than in semiconductor devices. In the early 1970's, the U.S. owned greater than 90 percent of the international market. By 1986, this had decreased to a market share of less than 50 percent. The U.S. SME industry is highly desegregated with several medium-size and many small companies, and is very vulnerable to competition, i.e., its staying power is limited in comparison with its largely integrated Japanese competitors.

Semiconductor manufacturers require domestic SME suppliers and these suppliers, in turn, require the presence of a large domestic market for their products in order to stay in business. Neither can exist with a large foreign dependency because that dependency provides an avenue for foreign competitors to deny access to the latest state-of-the-art and to essential sources of revenue. Thus the revitalization of the U.S. SME industry is essential to the maintenance of semiconductor technology competitiveness.

3.4 Effects on Downstream Industries

Downstream industries are those which use the products of the semiconductor industry. These products are now pervasive in almost all industries, but perhaps the most important for the purposes of this study are the telecommunications, control, and computer industries.

A strong domestic semiconductor industry is a prerequisite to a strong position in these downstream industries since the ability to perform competitive services and sell competitive products depends upon access to the most advanced semiconductor devices. Since the superiority of U.S. military forces depends upon superior intelligence, command, and control systems to multiply the effectiveness of force application, foreign domination of the computer, communication and control industries would have very profound implications for the Department of Defense. Further, the pervasiveness of these downstream industries in a modern economy implies that such dominance could be a major threat to the overall economic health of the United States in the decades ahead.

3.5 Effects on Human Skills and Resources

Young people are not easily attracted to a field if no domestic industrial base exists in that field upon which to build a career. A competitive semiconductor industry is therefore essential in order to attract the individuals necessary for maintaining a competitive technology base in the area. Further, the reservoir of human skills and expertise developed in the semiconductor industry is necessary not only for this industry, but also for new and perhaps not-yet-invented industries related to it. These skills cannot be retained and developed in academia alone.

4.0 RECOMMENDATIONS

4.1 The U.S. will depend to a large degree upon foreign sources of microelectronics hardware and technology to meet its defense needs unless measures are taken to help this country recapture and retain leadership in semiconductor manufacturing technology. To do so, the Task Force recommends that the Department of Defense take the following specific actions:

1. Support the establishment of a Semiconductor Manufacturing Technology Institute which would develop, demonstrate, and advance the technology base for efficient, high-yield manufacture of advanced semiconductor devices, and to provide facilities for production of selected devices for DoD needs. Such an institute could have an important impact not only on DoD but in the commercial market as well when member firms transfer technology to their own applications. The initial capitalization of the Institute by its industrial members would be on the order of $250 million, and support of approximately $200 million per year for five years would be provided by the Department of Defense. This is the principal and most crucial recommendation of the Task Force.

a. The DoD should stimulate the industry to help itself through the above Institute by facilitating the formation of an industry consortium. The stimulus could take the form of annual contracts for the development of selected production processes, equipment, materials, and devices. The existence of this Institute would, in turn, satisfy certain DoD needs.

b. A permanent Institute staff would be supplemented by committed personnel on loan for extended periods by the participating companies. The loaned staff would lead the transition of information and experience from the Institute to their own companies.

c. The 64 megabit DRAM represents an appropriate technology upon which the Institute could focus its efforts for the development of advanced manufacturing techniques. Focus needs to be placed on achieving quantum advancements, one of which would be to produce a means of adding competitive manufacturing capacity in smaller increments of output which would in turn be less demanding of investment capital.

d. The consortium would work with the U.S. Semiconductor Manufacturing Equipment industry to develop and test new equipment in a production environment to confirm its suitability for high volume production by a variety of producers.

e. Emphasis would be placed on facilitating the transfer of the advanced manufacturing process developed by the Institute into the manufacturing lines of its member organizations.

f. In order to demonstrate high-volume low-cost manufacturing capability, the consortium would be required to sell the advanced products it produces in limited numbers in the competitive market.

g. Initial capitalization may be made by direct investment by the participating companies, by a low-interest government-backed loan, or a variety of other alternative mechanisms.

h. The Department of Defense would assign its own researchers to the facility staff and would have the right to a limited share of the production output to fill its own needs.

i. Membership would be constrained to firms having beneficial ownership in the U.S.

2. Establish at Eight Universities Centers of Excellence for Semiconductor Science and Engineering built upon current NSF, DoD, and commercial consortium programs, to devise, develop, and demonstrate new and innovative approaches to device design and manufacturing that lower costs and improve performance and quality. Cost of this program to the Department of Defense would be about $50 million per year.

In addition to research and development, these centers would promote the training of highly qualified students who would become the foundation of a continuing excellence in semiconductor manufacturing expertise.

3. Increase DoD spending for research and development in semiconductor materials, devices, and manufacturing infrastructure by about 25 percent per year for four years. The cost of this increase will be $60 million in the first year, growing to $250 million in the fourth year.

The overall purpose of this program should be the development and demonstration of approaches to integrated circuit manufacture that lower cost and improve quality and performance.

In addition, support of the Strategic Materials Initiative now being considered by the DoD is recommended. This focus on a broad range of materials opportunities is complementary to proposals made herein.

4. Provide a source of discretionary funds to the Defense Department's semiconductor suppliers to underpin a healthy industrial research

and development program. The cost of this activity should be about $50 million per year and should be restricted to work directly related to semiconductor needs of the Department of Defense.

> These funds would fill the same critical role for the semiconductor suppliers as does Independent Research and Development for the Department of Defense's prime contractors.

5. Establish under the Department of Defense a Government/Industry/University forum for semiconductors to provide a common meeting ground for assessment of the above program and to facilitate joint action on problems of semiconductor research, development, and production of specific interest to national defense. Cost of this recommendation to DoD should be about $200 thousand per year, principally for administrative costs.

> This Forum should continually assess the state of the domestic microelectronics technology base; competitiveness of the U.S. semiconductor industry; education and research in related fields; and effectiveness of this and related government programs.

Due to the national importance of the semiconductor industry's competitiveness to the nation's economy as a whole, it is recommended that an advisory group be established under OSTP, to include representatives from NASA, DoE, DoD, Departments of Commerce and Transportation, and other appropriate organizations, to formulate a comprehensive and coherent strategy for legislative, administrative, and management action to reverse the trend toward the export of semiconductor manufacturing and technology leadership. Representatives of industry and academia should be included either as full members or as advisors. Development of such a strategy would have broad implications since the semiconductor industry is the keystone of the growing information industry, which itself could be a keystone of the twenty-first century economy.

The pace of advancement of semiconductor technology is such that an entire new generation of key devices is introduced every two to three years. The current position of the overall U.S. merchant semiconductor industry is concluded to be very tenuous in terms of present manufacturing capability. Steps to preserve its viability must be taken with dispatch.

SECTION II.

BRIEFING CHARTS

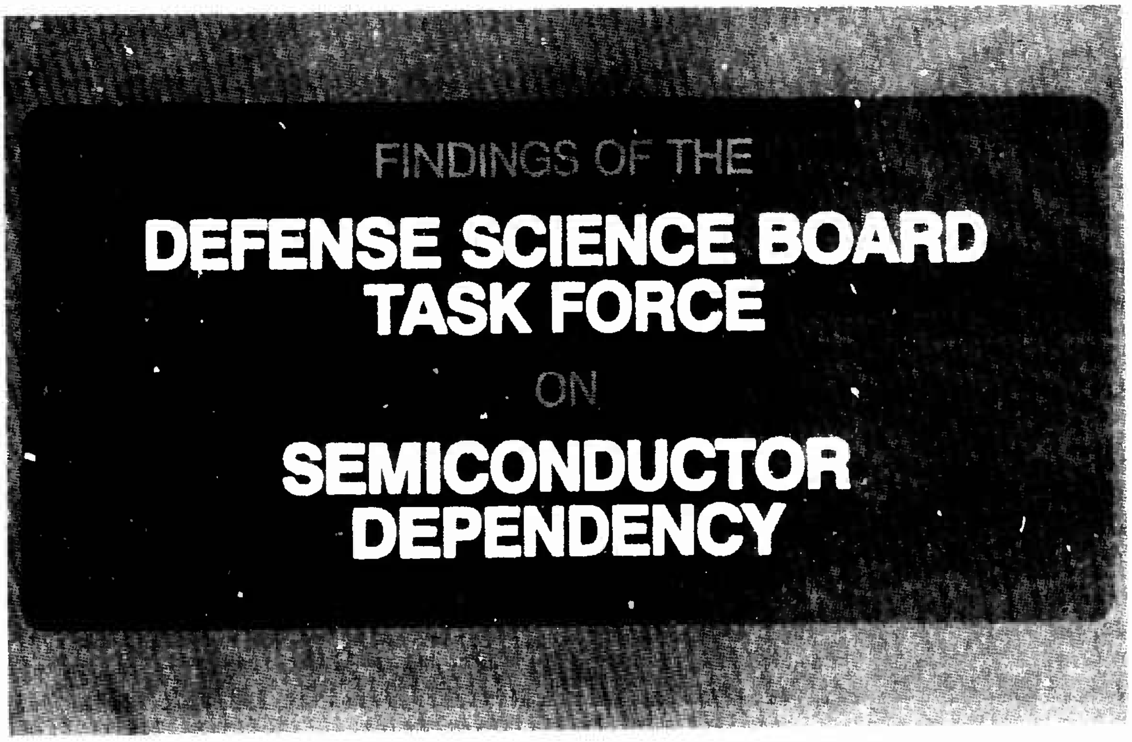

FINDINGS OF THE
DEFENSE SCIENCE BOARD
TASK FORCE
ON
SEMICONDUCTOR
DEPENDENCY

FIGURE 1.

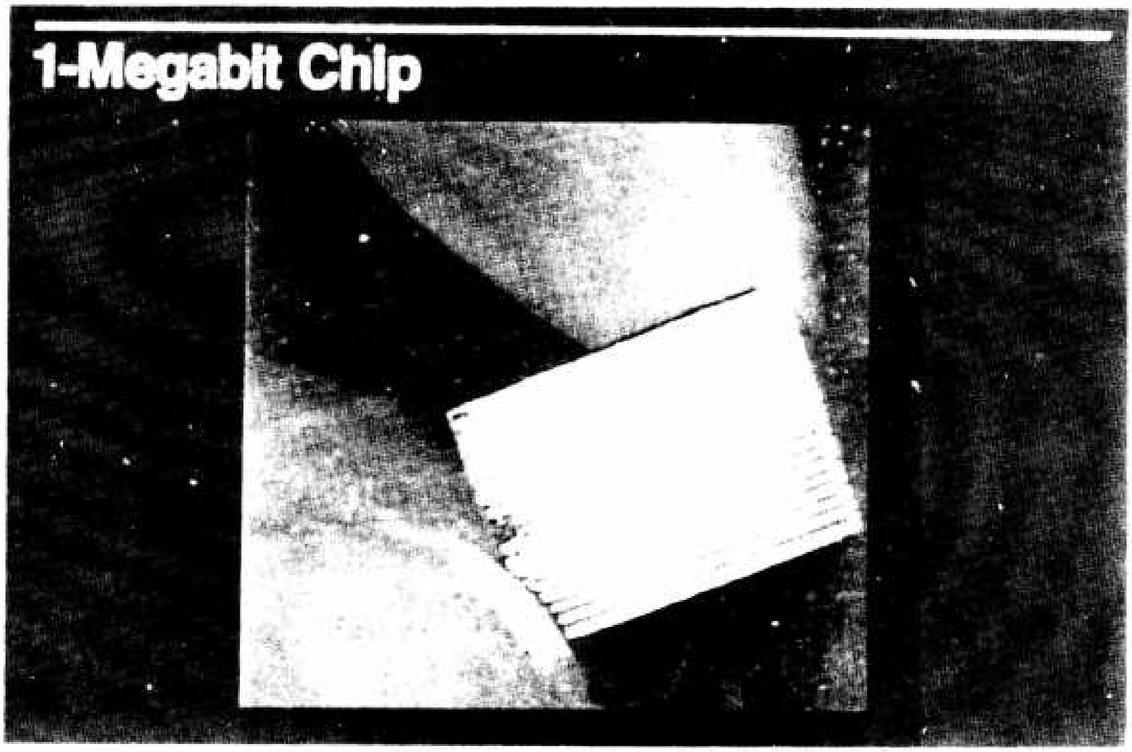


FIGURE 2.

The most advanced semiconductor memory chip commercially available at the present time is the one megabit Dynamic Random Access Memory (DRAM). These chips, capable of storing approximately one million bits of information on a silicon wafer about one-quarter of one inch on a side, in many respects represent the bellwether of the semiconductor industry. Not only do such chips present state-of-the art challenges in design and function, but, because of the abundance in which they are utilized, place state-of-the-art demands on manufacturing technology as well. DRAM's find widespread use in virtually all types of military and commercial electronic products.

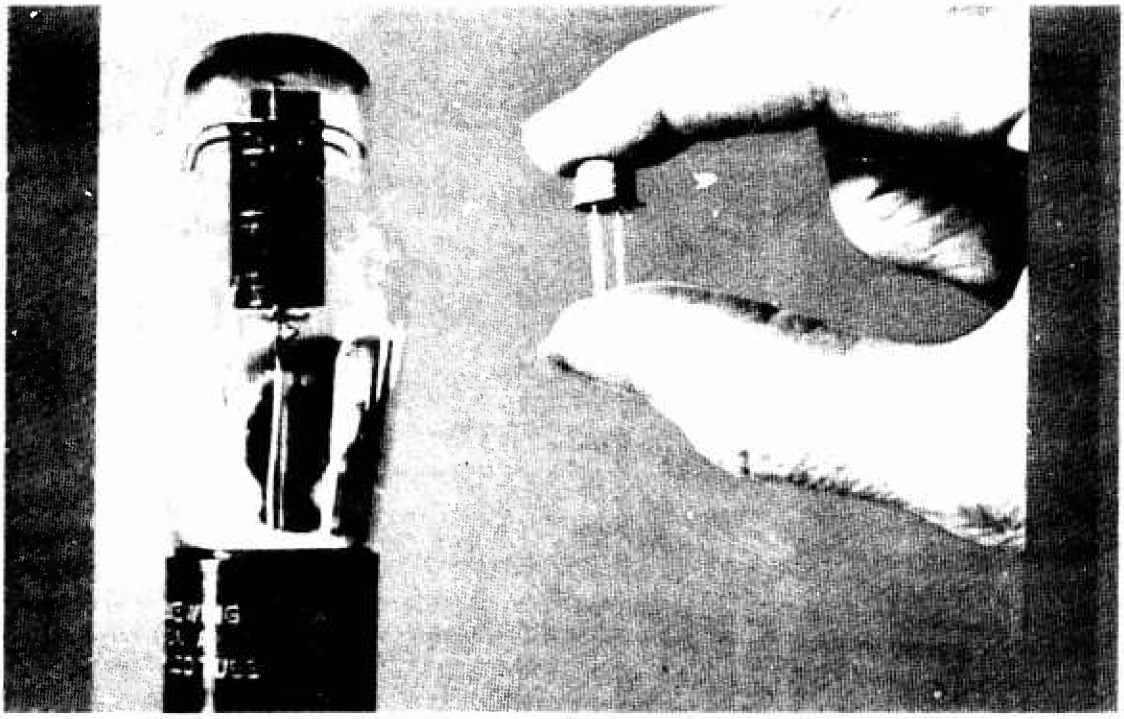


FIGURE 3.

Semiconductor chips are functional descendants of the vacuum tube and the transistor. Using modern manufacturing technology, it is possible to place on a single silicon chip the functional equivalents of millions of vacuum tubes. By the end of the century, it may be possible to store a billion bits of information on a single chip. A "bit" is the smallest unit of information; a large book contains on the order of one million bits.

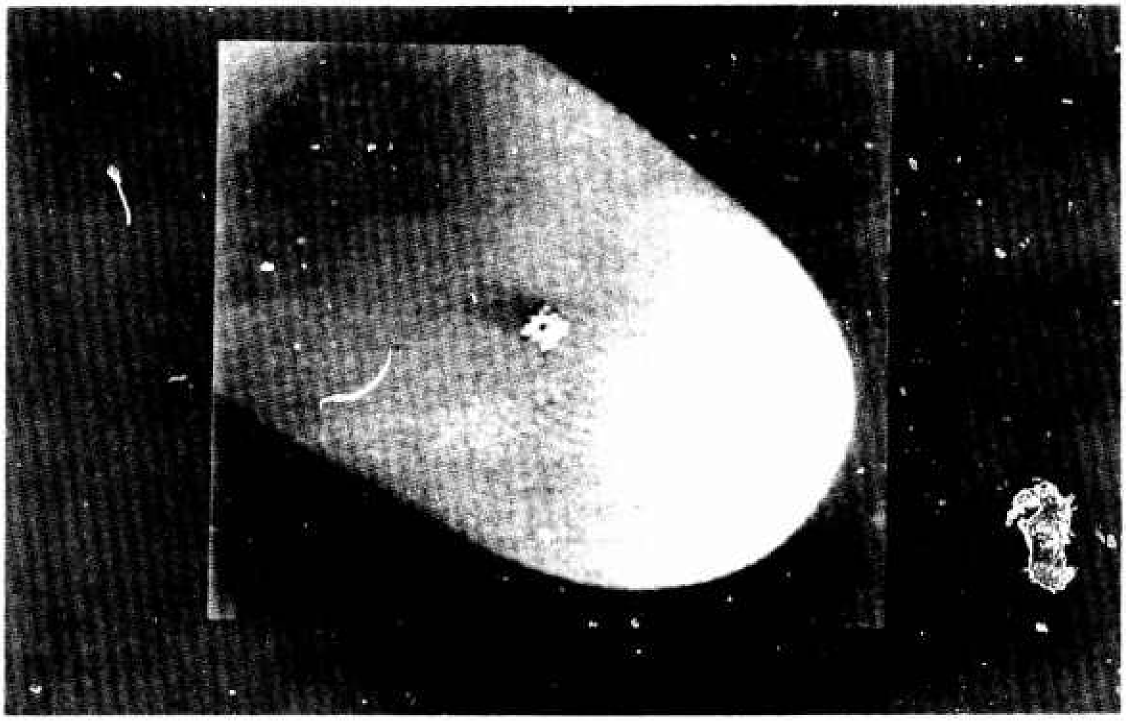


FIGURE 4.

Semiconductor chips, or integrated circuits as they are more formally known, offer numerous advantages including small size, low cost, minimal power demand, high reliability, and very high speed. They have been referred to not inappropriately as the 'industrial rice" or as "twenty-first century crude oil."

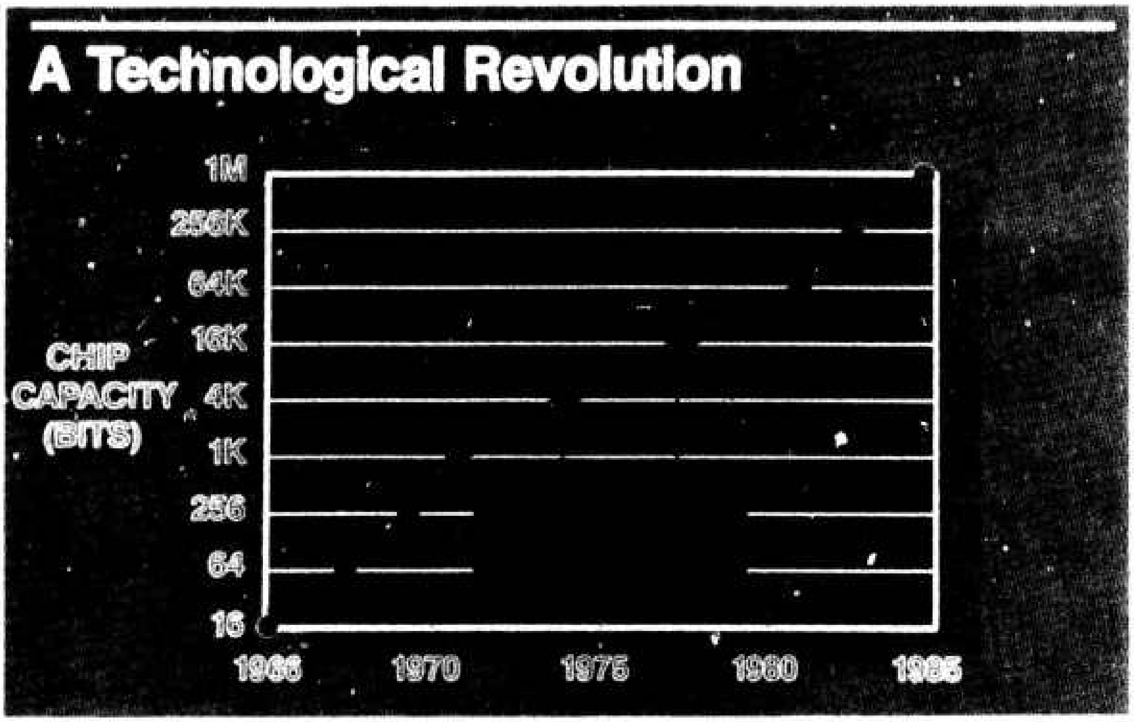


FIGURE 5.

The rate of advancement in semiconductor technology has been such that a new generation (a factor of four increase in capacity) of Dynamic Random Access Memory chip has been introduced approximately every 2-1/2 years. Each successive generation has required altogether new tooling throughout the industry, with the "hurdle cost" of such tooling increasing substantially as each new plateau is reached. To tool a modern, one megabit production line costs well in excess of $100 million to provide the minimum commercially viable output volume. This rapid pace of change is a fundamental underlying factor in both the commercial and military impact of semiconductors as well as the current health of the U.S. semiconductor industry.

FIGURE 6.

For several years events have been unfolding which place the long-term health of the U.S. semiconductor industry in grave jeopardy. Principal among these is the competitive pressure which has emerged from Japan. In addition, Korea is a growing factor in the future marketplace and European producers are dropping further behind. Also, significant to the current study, which by charter focuses on national defense implications of the United States' domestic semiconductor capability, is the fact that the Soviet Union has only a minimal capability to produce advanced semiconductor devices of its own. The state of the art for production integrated circuits in the Soviet Union is a chip capacity of 64K (sixty-four thousand bits) ... about five years behind the U.S.

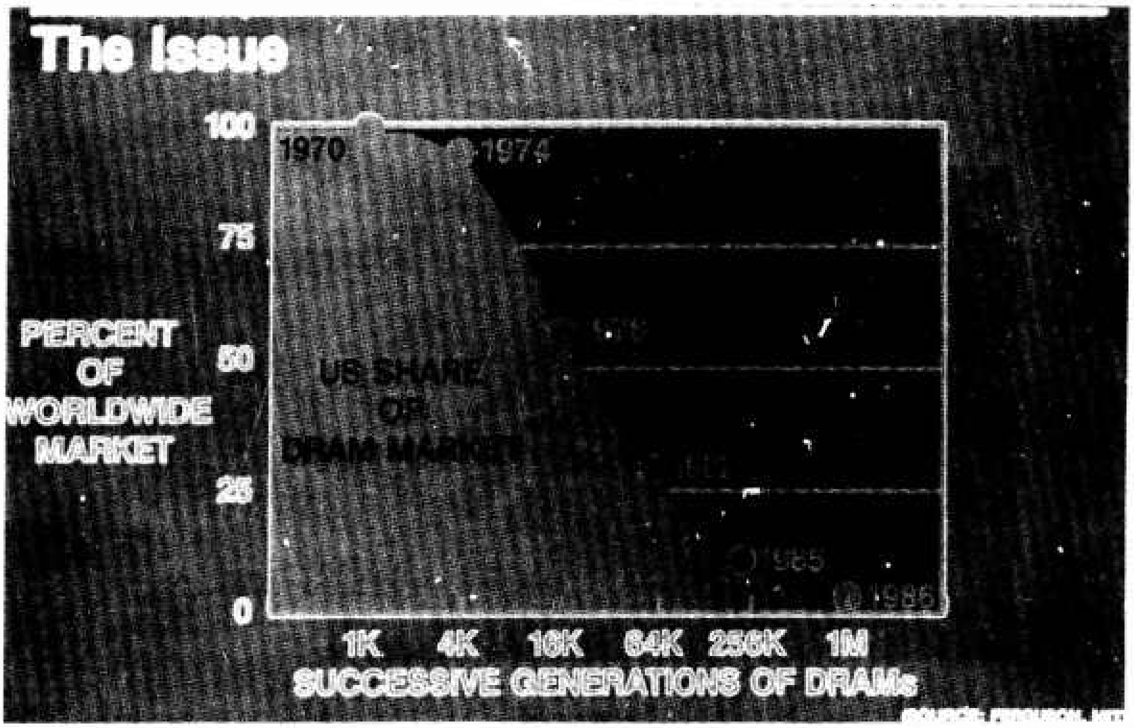


FIGURE 7.

Although U.S. producers still possess a substantial portion of the overall worldwide merchant semiconductor market (60 percent in 1975 declining to 45 percent in 1986 ... with Japan increasing from 20 percent to 45 percent in the same period), U.S. performance in the pivotal Dynamic Random Access Memory arena is disconcerting. DRAM's generally place state-of-the-art demands on manufacturing processes and comprise the most competitive segment of the market in terms of production volume. In essence, the U.S. has gone from a position of total dominance in DRAM production to one of minority influence over a period of a decade. Most U.S. manufacturers have been forced to retreat into periph^ral, "niche" markets, or to abandon the integrated circuit commodity business altogether.

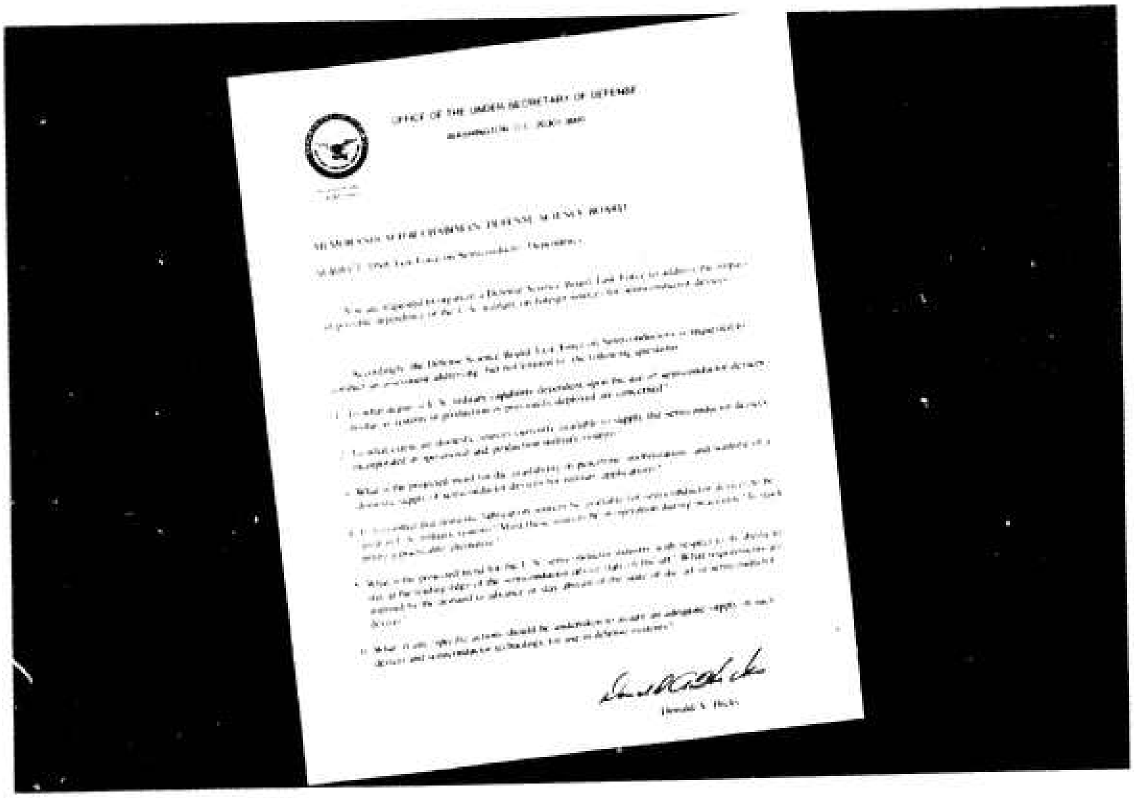


FIGURE 8.

Because of the growing trend among U.S. semiconductor producers themselves to establish factories in the Pacific rim which might not be available in time of military mobilization, to withdraw from the business altogether, or to be acquired by foreign firms, the Under Secretary of Defense for Research and Engineering requested that a Task Force of the Defense Science Board be established to assess the impact of these trends on national defense and to make appropriate recommendations stemming from the review.

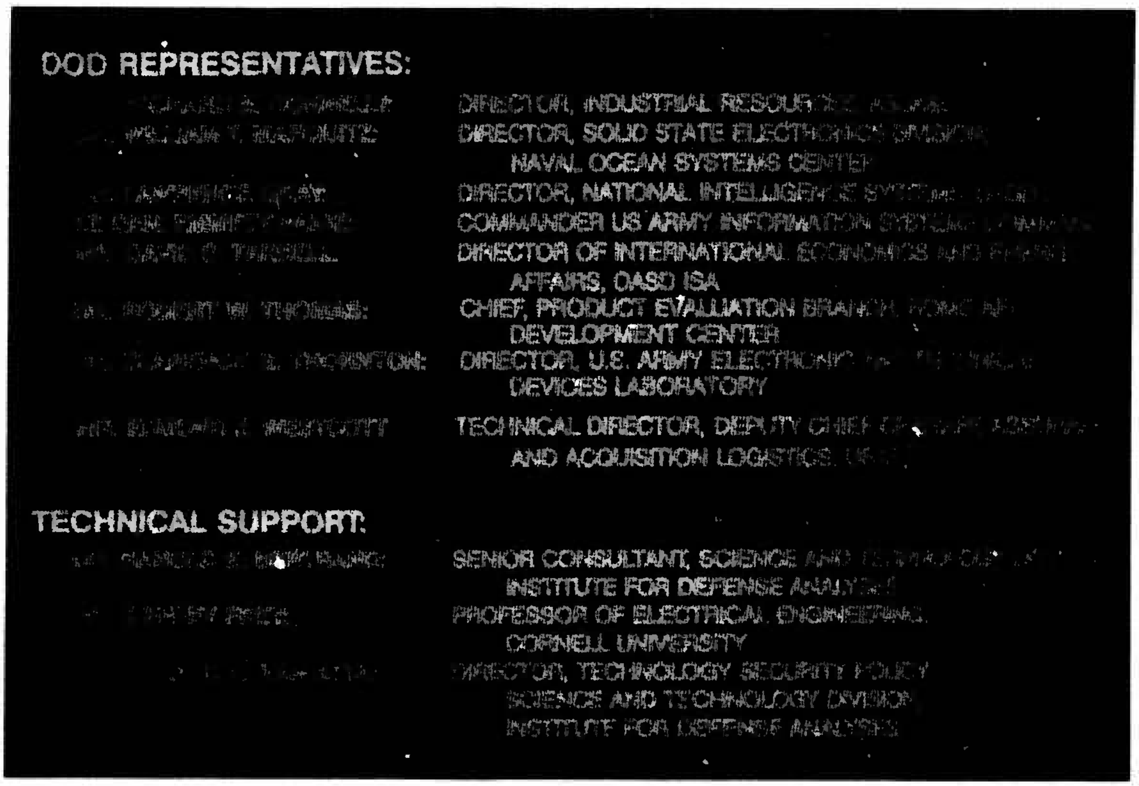


FIGURE 11.

Technical support was provided throughout the study by individuals with the Institute for Defense Analyses and the National Science Foundation. Administrative support was provided by Palisades Institute for Research Services.

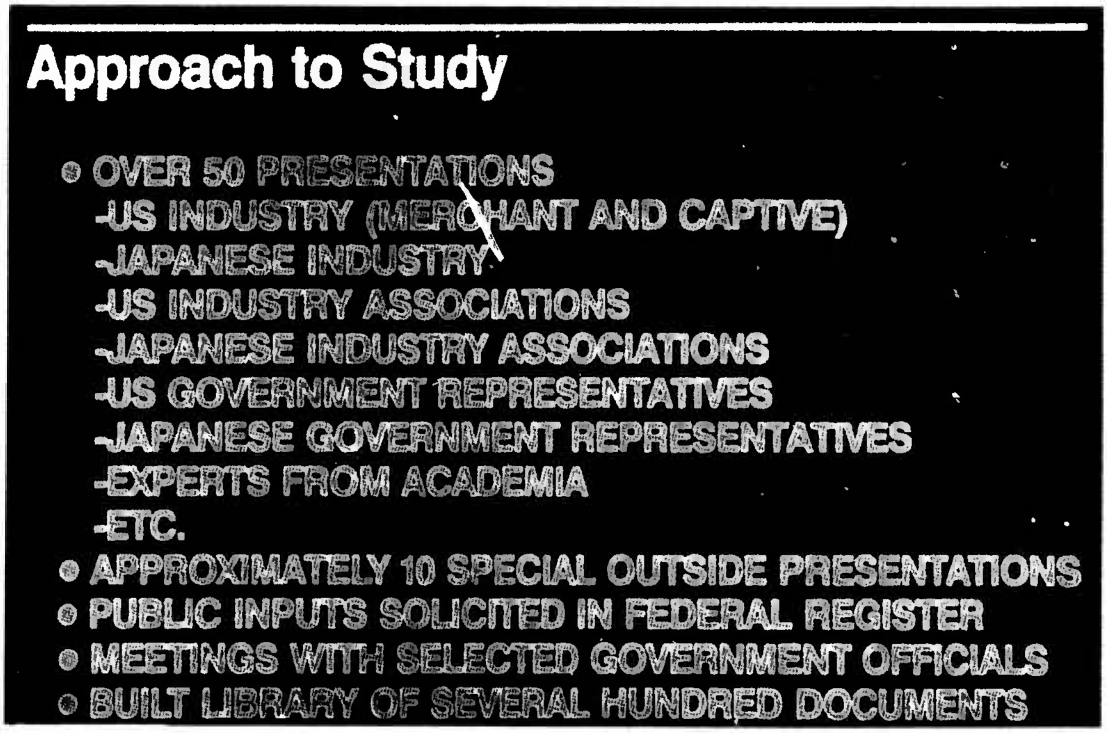


FIGURE 12.

The members of the Task Force and its Industry Advisors received over 50 presentations during a period of some ten months. In addition, a number of separate meetings were held with individual experts to address specific factors affecting defense semiconductor dependency. Public inputs were solicited through the Federal Register and additional briefings were conducted to hear the views of concerned observers. It should be noted that many of these concerns fell outside the purview of this particular Task Force; however, may well be of considerable importance in their own right. One such example is the status of the magnetic storage industry which is said by some to parallel that of the semiconductor industry.

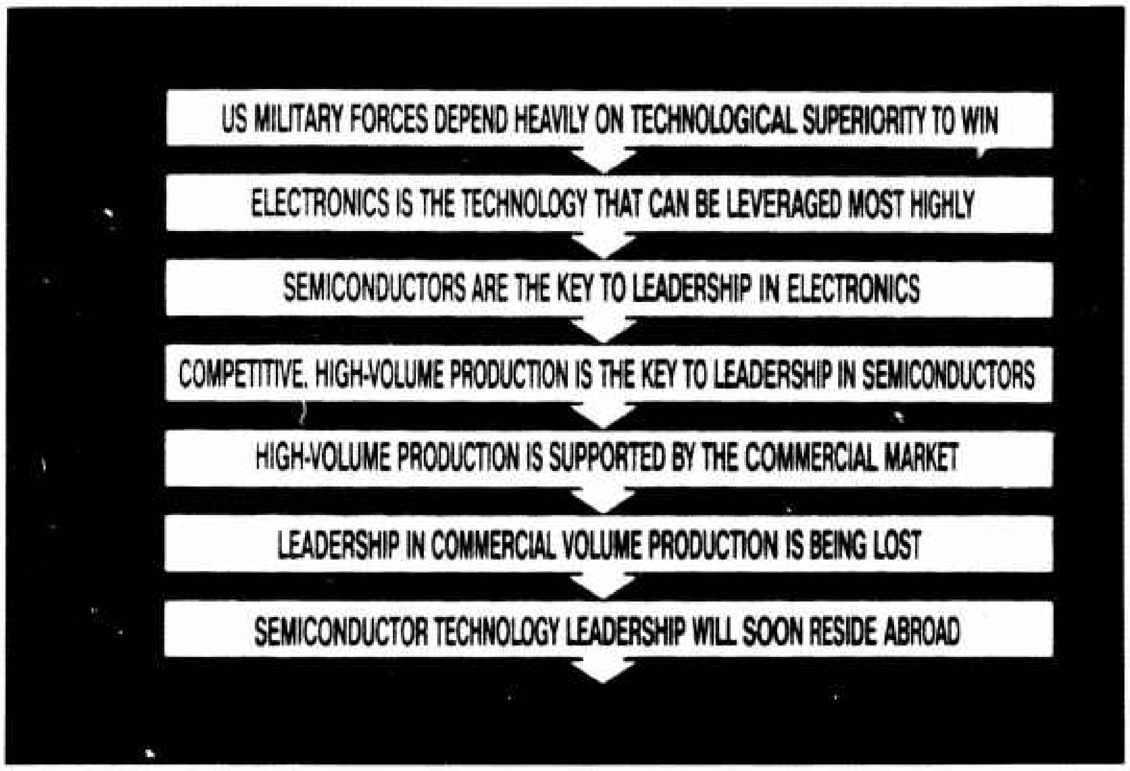


FIGURE 13.

The basic findings of the Task Force are summarized in the above chart. In particular, it is noted that U.S. military forces depend heavily upon technological leadership in order to deter and to win. Although many technologies make important military contributions, electronics appears to be the most highly leveraged in terms of producing quantum operational gains. Semiconductors, in turn, are clearly the leading edge of electronic progress -- and volume production represents the key to leadership in semiconductor devices because of the need to drive down unit costs and to produce in the very large quantities needed to meet user demands. The commercial marketplace, as opposed to defense needs, comprises the pacing factor insofar as semiconductor production is concerned. Leadership in commercial production is, however, being lost by the United States. Technology leadership is also moving abroad because of its dependency on the volume production base provided by commercial pursuits, both for funding and for the development of process technology. Clearly, the Department of Defense has no inherent responsibility for the commercial viability of the U.S. semiconductor industry. Unfortunately, however, the Department of Defense is unlikely to be able to fulfill its requirements, both in terms of hardware and technology, without a strong domestic semiconductor industry. Thus, DoD's self-interest is inextricably tied to the vitality of the U.S. semiconductor industrial base.

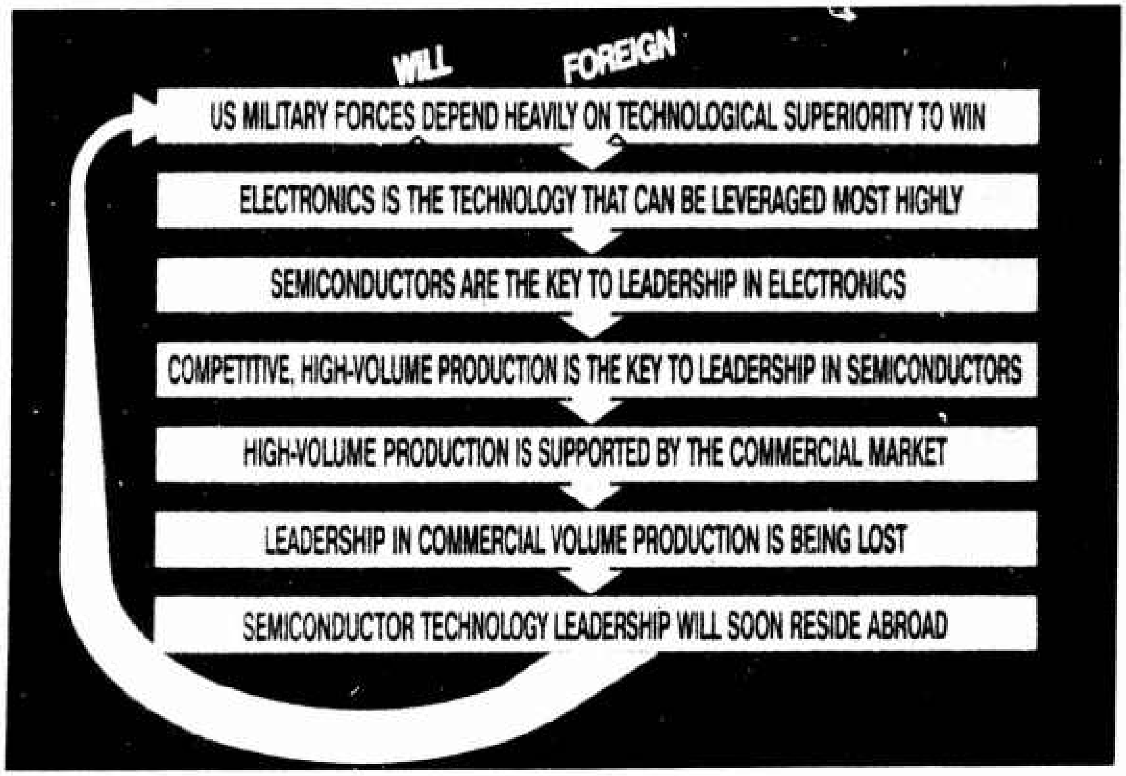


FIGURE 14.

It is the principal finding of the Task Force that if current trends are permitted to persist, U.S. military forces within the next decade will be dependent upon foreign technology for the critical capabilities which underpin the nation's strategy for prevailing in case of military conflict.

The remainder of this report addresses the individual factors enumerated above and concludes with an assessment of the causes and possible solutions to the dilemma which ensues.

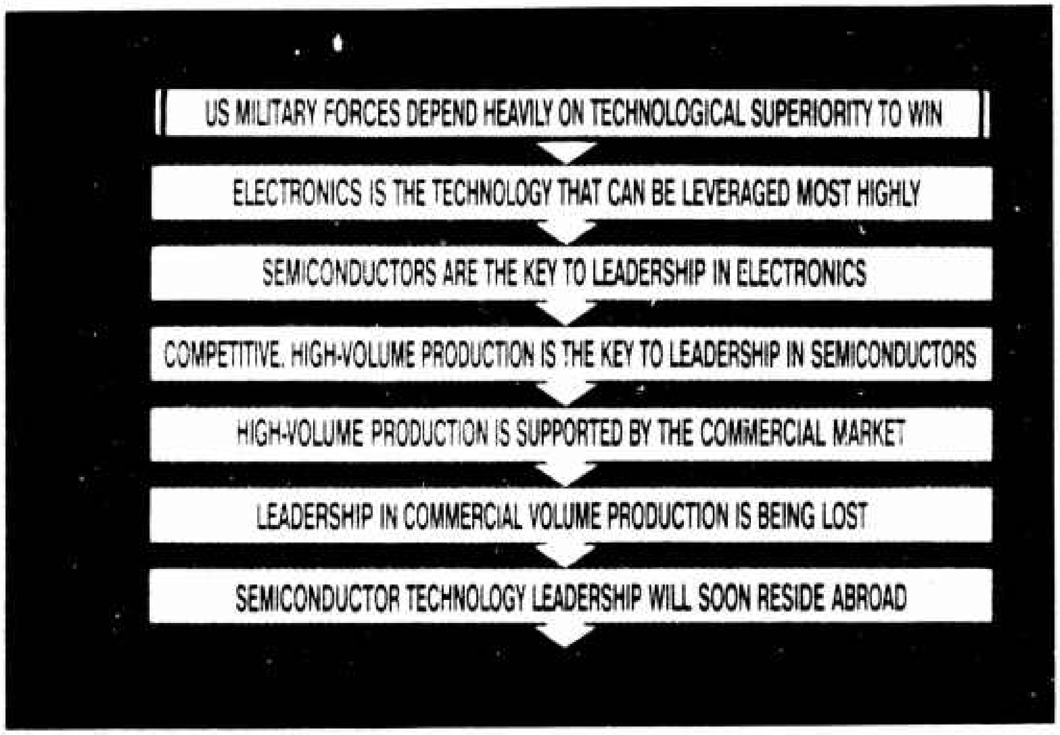


FIGURE 15.

U.S. military forces depend heavily on technological superiority to win.

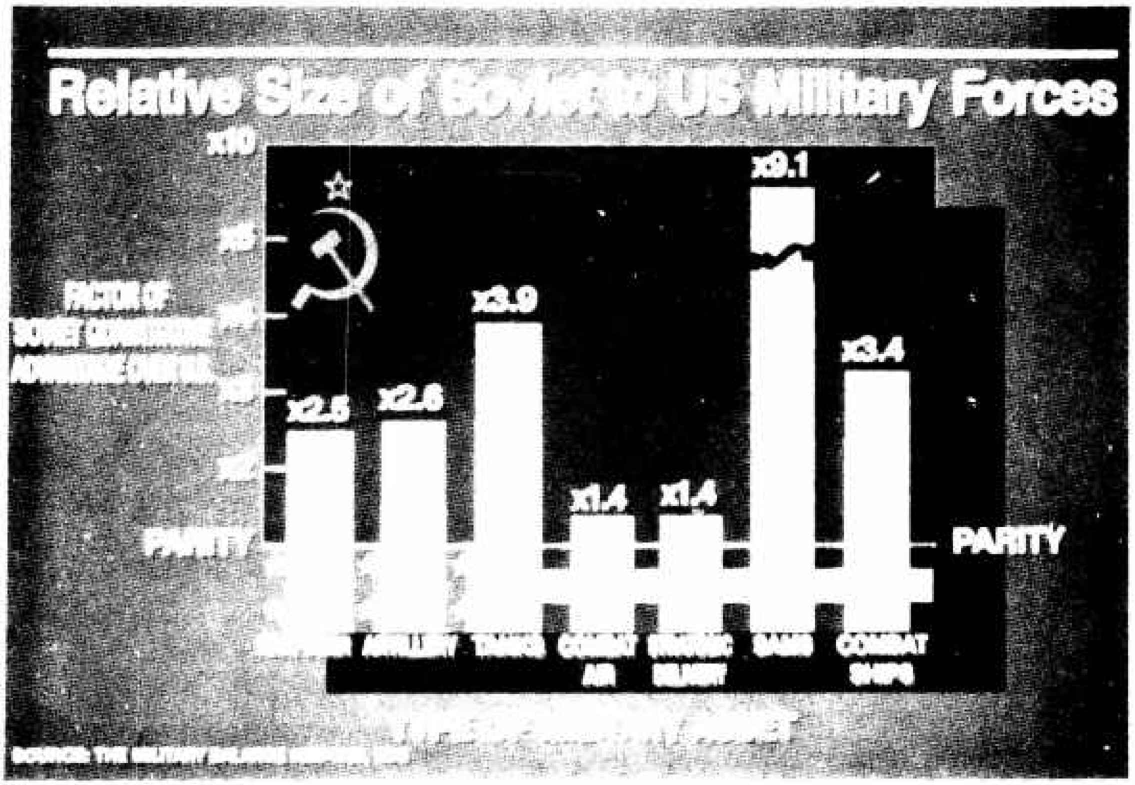


FIGURE 16.

In quantitative terms, Soviet military forces generally outnumber their U.S. counterparts. When viewed in terms of Warsaw Pact vs. NATO forces, the result is generally similar although the differences are somewhat lessened. For a number of years, the U.S. has stated that its policy for offsetting this numerical disadvantage is founded in large part upon maintaining technologically superior forces.

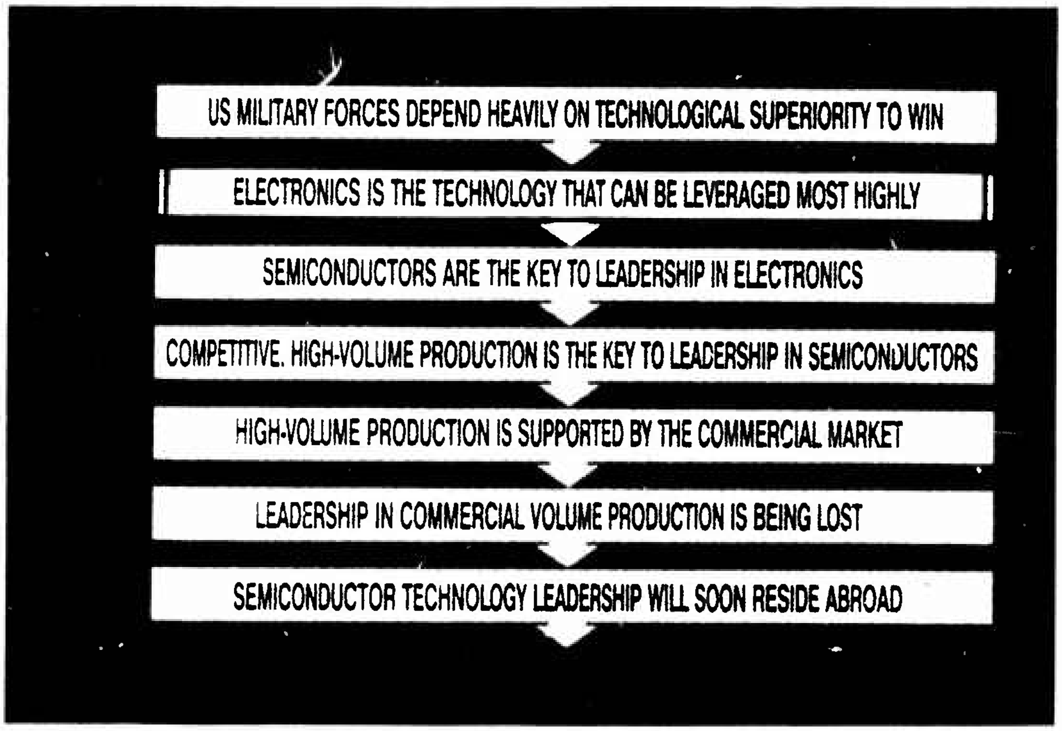


FIGURE 17.

Electronics is the technology that can be leveraged most highly in military terms.

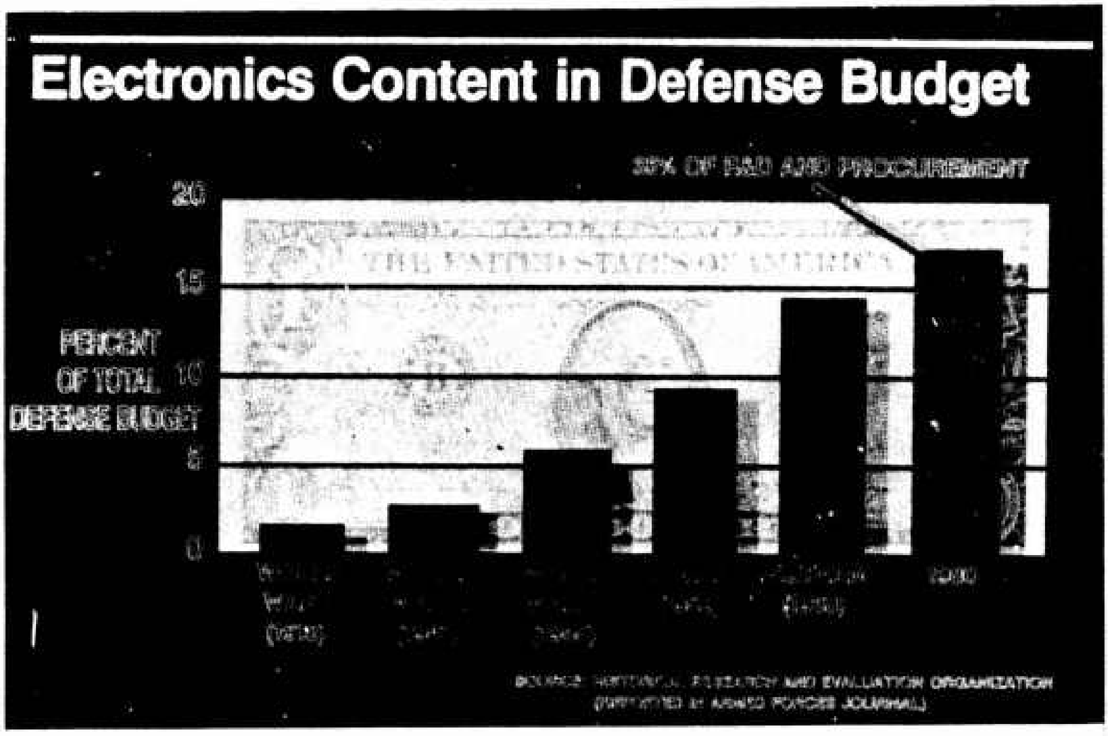


FIGURE 18.

Although a number of technologies contribute in important ways to maintaining the strength of modern military forces, it is probable that electronics technology is dominant among these as a discriminator in combat capability. This is reflected by the fact that the electronics component of the defense budget has increased progressively until today it represents approximately 35 percent of the research, development and procurement funds allocated to the Department of Defense. The technological engine behind much of the overall electronics usage in defense systems is the semiconductor. The sections which follow illustrate examples of the importance of electronics to modern defense capabilities and, subsequently, the role of semiconductors in these electronics. Further examples are included in the "Supplemental Briefing Charts" section beginning at page 91 herein.

FIGURE 19.

Many examples exist where quantum gains in military capability have been achieved by the application of modern electronics technology. For example, the replacement of ground-based radar ballistic missile warning systems with satellite-borne sensors has more than doubled warning time and greatly expanded geographical coverage.

FIGURE 20.

The advent of lightweight but highly capable electronics has permitted the replacement of ground-based radar surveillance systems with airborne radars capable of monitoring over one million cubic miles of airspace from a single platform ... without the customary gaps left exposed to low altitude penetrators.

FIGURE 21.

Modern electro-optical fire control systems enable tactical attack aircraft to engage several targets on a single pass even in night-time conditions. So important to the F-16 aircraft are its on-board electronics that the aircraft is aerodynamically unstable and is made flyable only through the use of advanced computer and automatic control systems.

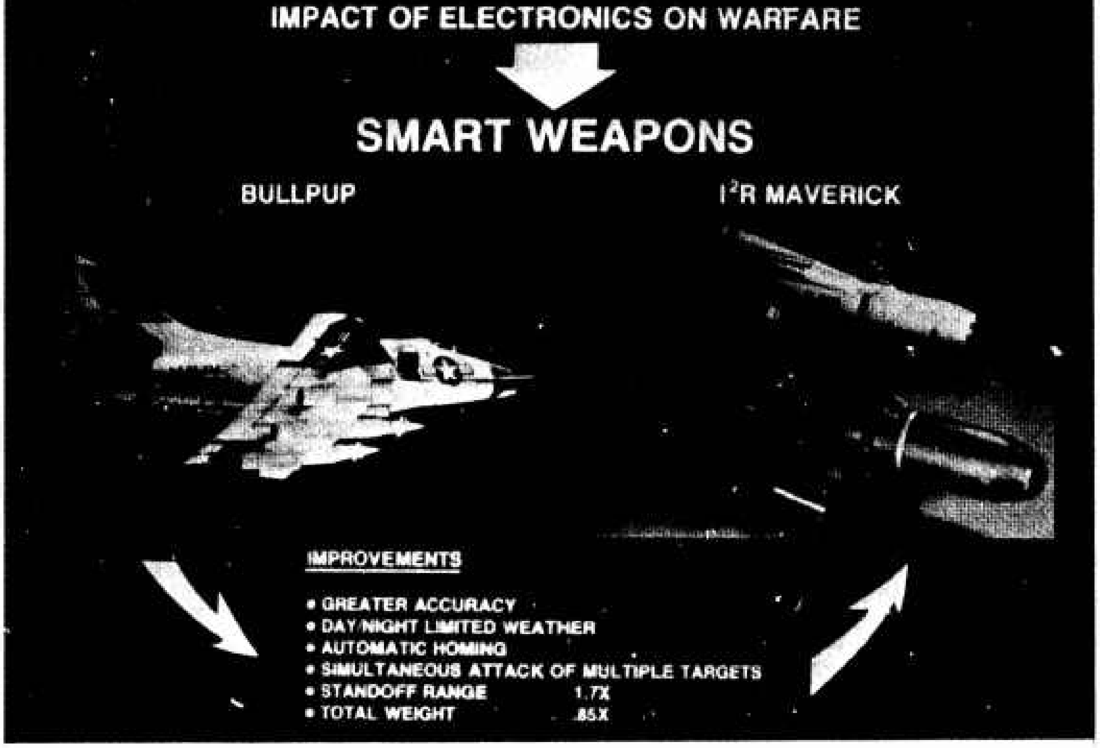


FIGURE 22.

Many other examples of the ubiquity of electronics in providing quantum advances in operational military capability can be cited. The advent of smart weapons is one particularly significant development which has been made possible by modern electronics technology. A force equipped with such ordnance can be shown to have the capability of a more conventionally equipped force of much greater size. Advances incorporated in the past few years enable autonomous tracking of targets and in some cases the achievement of delivery accuracies which enable selection of the specific location on a tactical target where a hit is to be produced.

FIGURE 23.

Modern electronics technology has had a profound impact even on such traditional weapons systems as the battle tank. Recent advancements include the ability to fight at night using only passive sensors, to shoot while moving, and to hit targets at extended ranges with the first round fired -- thereby greatly reducing exposure of friendly tanks.

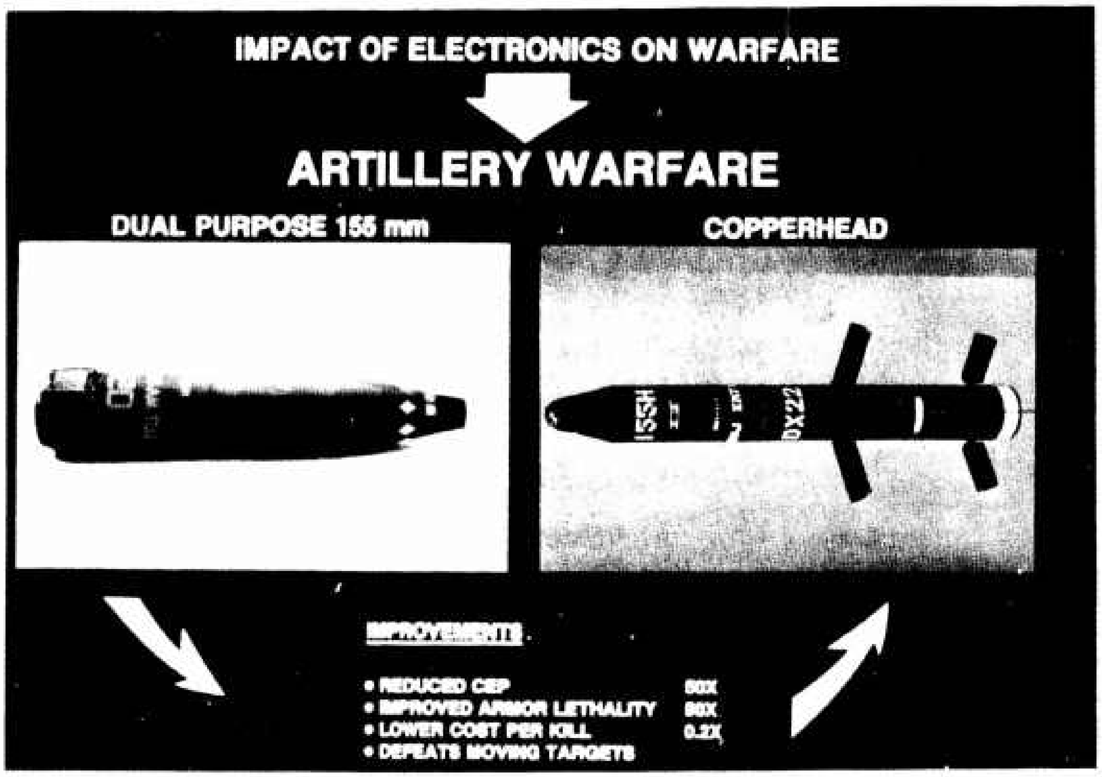


FIGURE 24.

The advent of solid state electronics has made feasible compact guidance systems which can withstand the 10,000 G environment associated with being fired from an artillery piece. In this instance, the operational capability achieved is not simply an improvement over prior capabilities but instead affords an altogether new use of artillery -- that is, to engage moving armored targets. It has been estimated that a single guided projectile engaging a moving tank will have about the same probability of hit as would some 2,500 unguided unitary rounds.

FIGURE 25.

The Navy's AEGIS system provides the capability to automatically detect and track large numbers of threatening aircraft and missiles and to engage them in a fraction of the time required by earlier fleet air defense systems.

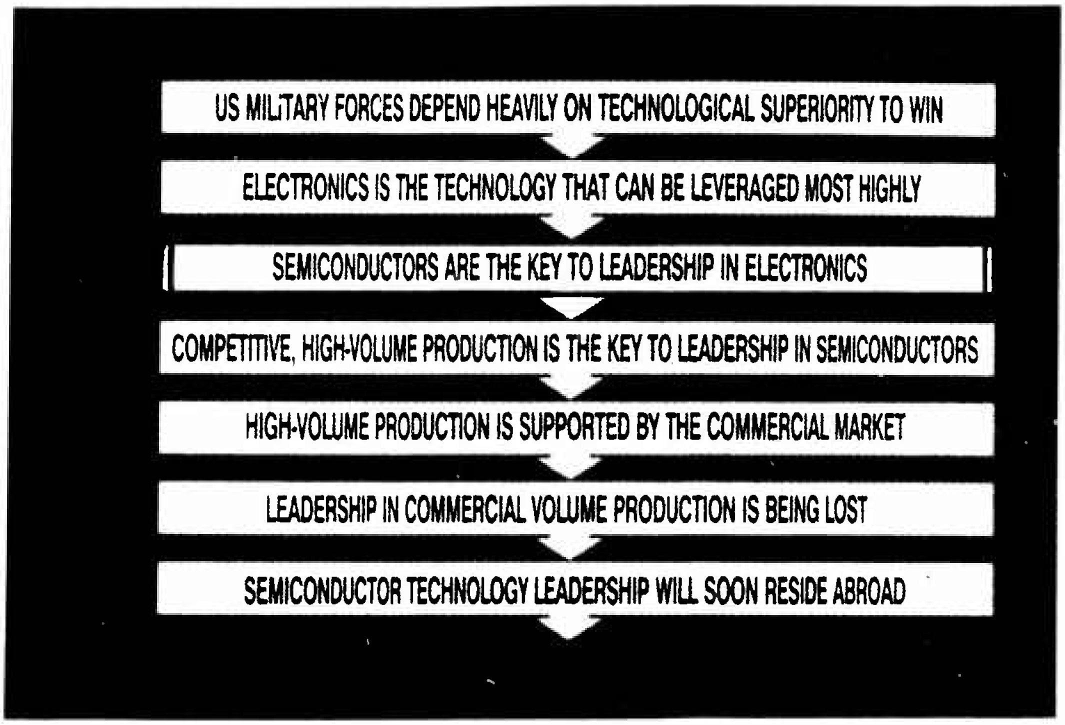


FIGURE 26.

Semiconductors are the key to leadership in electronics.

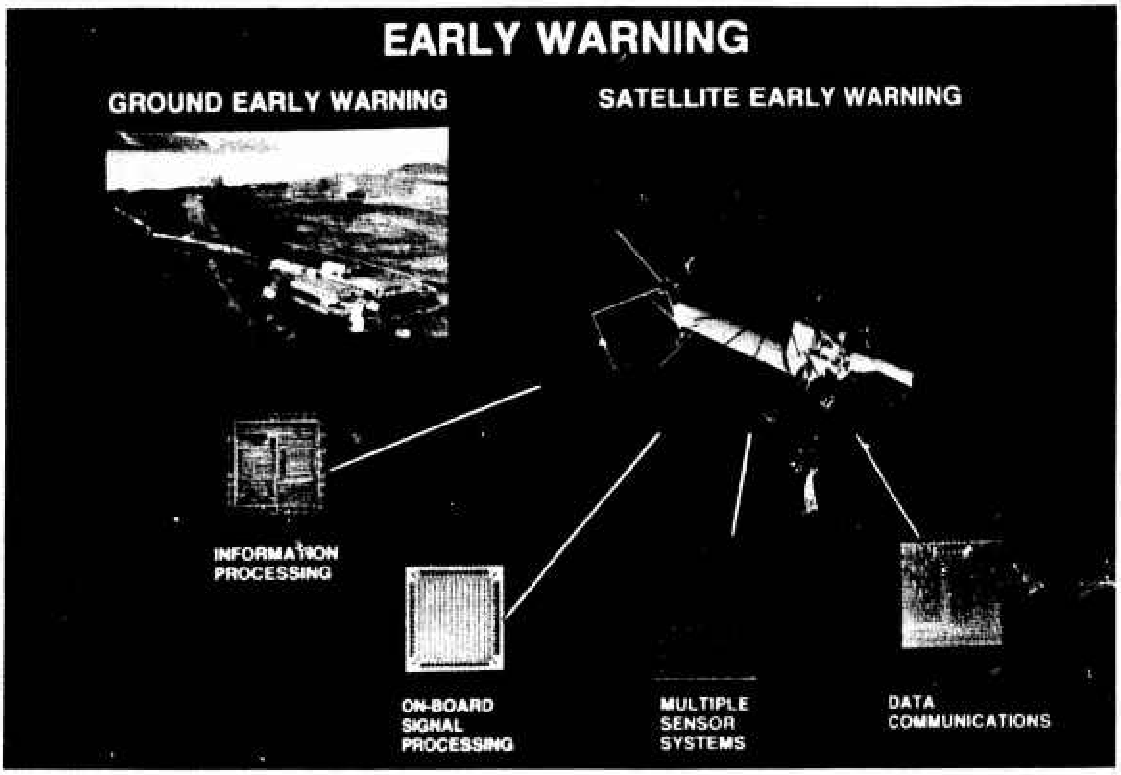


FIGURE 27.

The sequence of figures which follows illustrates the ubiquity of semiconductor devices in making possible the advancements in military capability illustrated in the preceding examples. Of profound importance is the fact that semiconductors are in essence becoming entire subsystems in themselves -- critical to modern military hardware.

FIGURE 28.

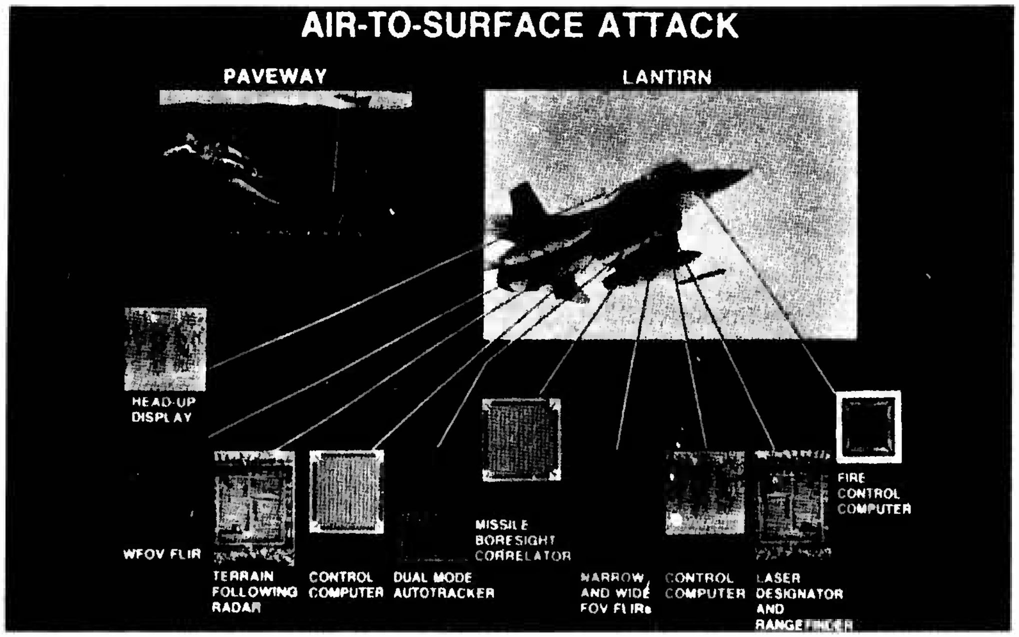


FIGURE 29.

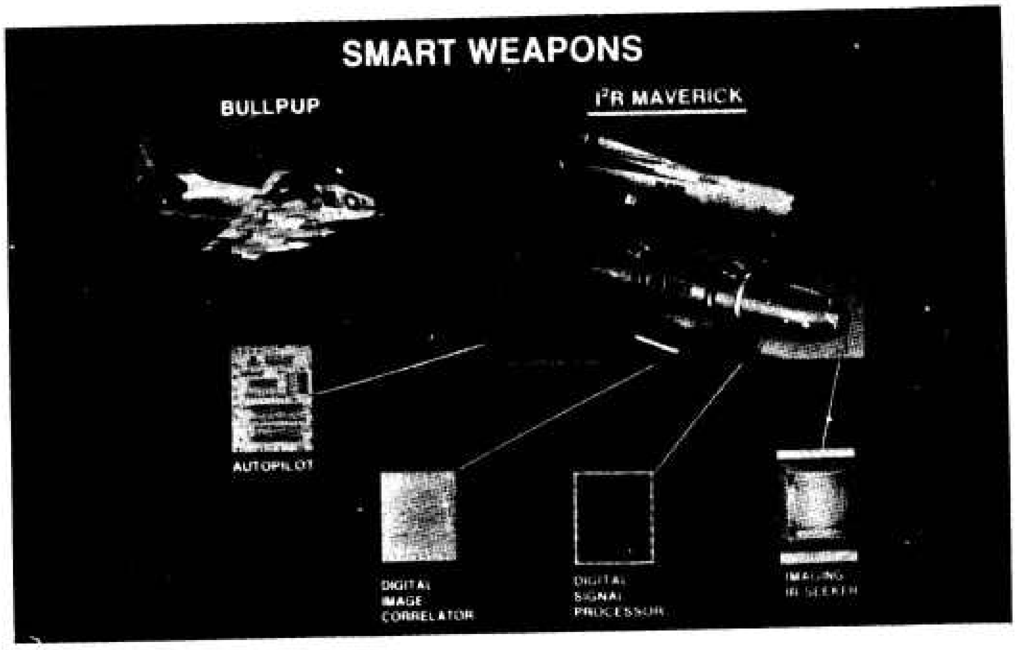


FIGURE 30.

FIGURE 31.

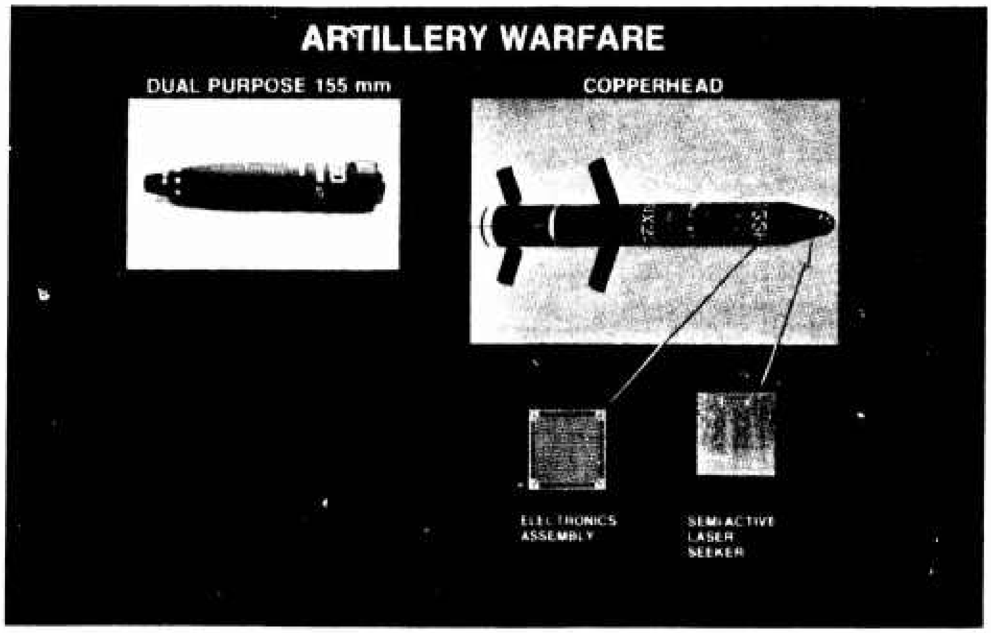


FIGURE 32.

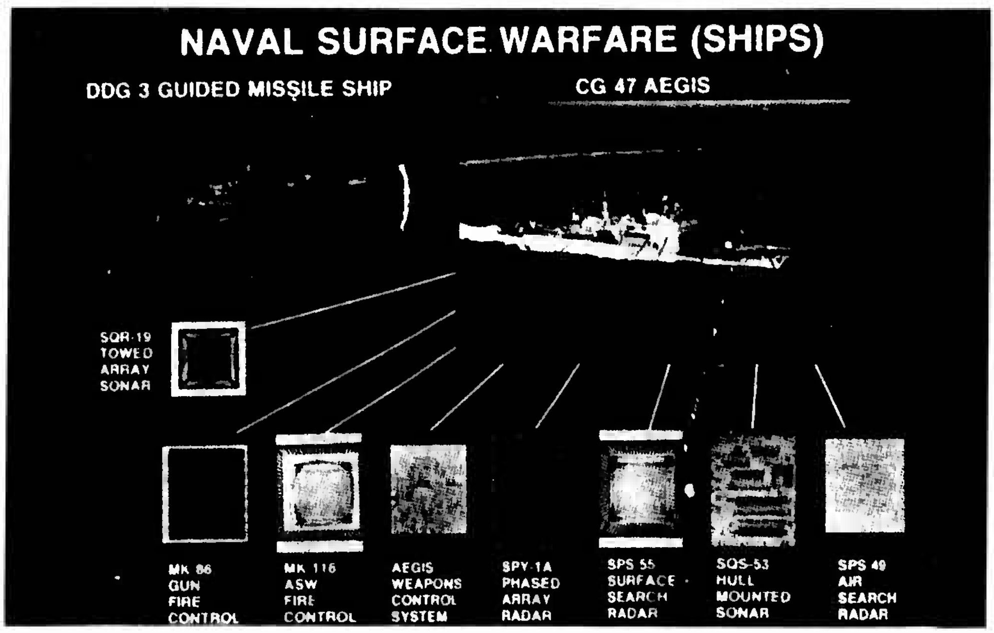


FIGURE 33.

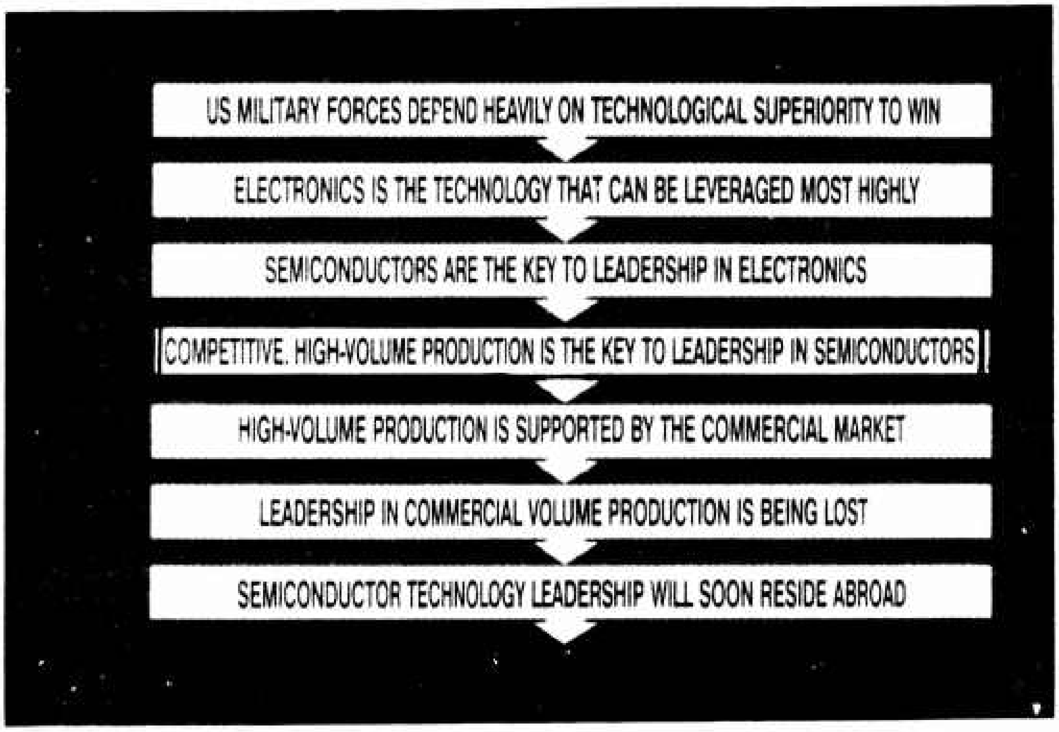


FIGURE 34.

Competitive, high-volume production is the key to leadership in semiconductors.

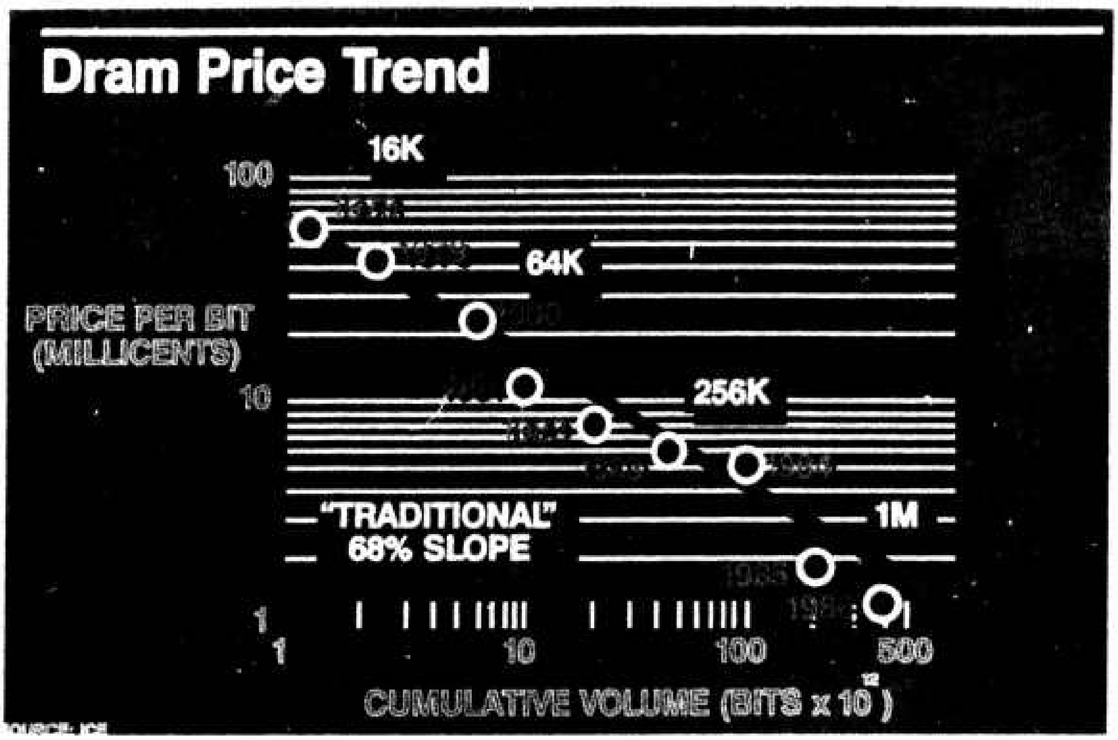


FIGURE 35.

The key to the widespread usage of integrated circuits is the ability to manufacture them in large quantities at very low cost. That is, manufacturing technology underlies the viability of most applications of semiconductor devices. This pressure has resulted in substantive improvements in production technology including a reduction in the last decade alone of about a factor of 100 in the price to store a single bit. For U.S. semiconductor manufacturers, and particularly those in the merchant market (i.e., providing chips for incorporation into end-items by others), manufacturing provides the "engine" which creates the income necessary to pursue ever advancing technology and to introduce successive generations of products. Manufacturing confronts the key technology issue of producing ever smaller feature sizes on a chip...with dimensions being approached of less than a micron.

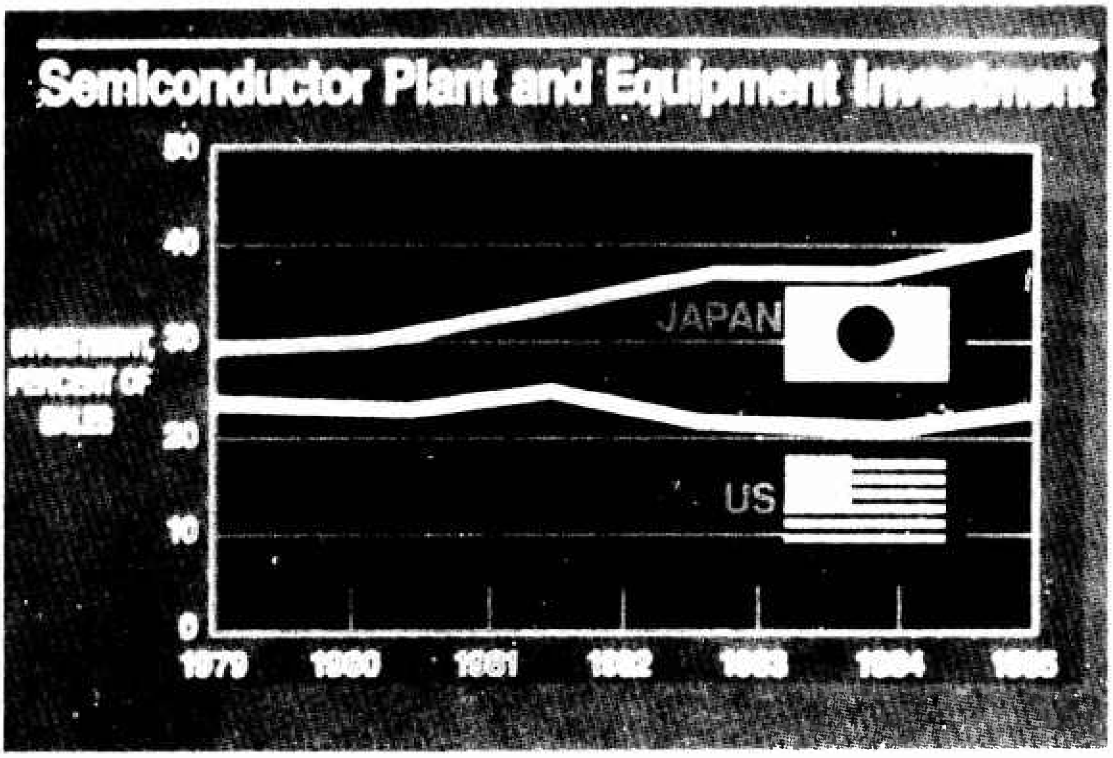


FIGURE 36.

Major demands for capital are imposed on the semiconductor industry since new production lines must be established every few years as successive generations of products are introduced. At the present time, the Japanese semiconductor industry is expending about twice the fraction of sales on new plant investment as is the practice among U.S. firms. This problem is exacerbated as the Japanese share of the total world market also increases ... such that today total expenditures by Japan for semiconductor plant and equipment exceed those of the U.S. by about 100 percent. It is a fundamental property of the industry that fixed costs are very large as compared with variable costs -- thus underlying many of the extraordinary pricing policies observed in the marketplace.

FIGURE 37.

Modern semiconductor production lines are highly automated and entail relatively limited human involvement -- both to assure consistency of quality as well as to support high volume, low cost output.

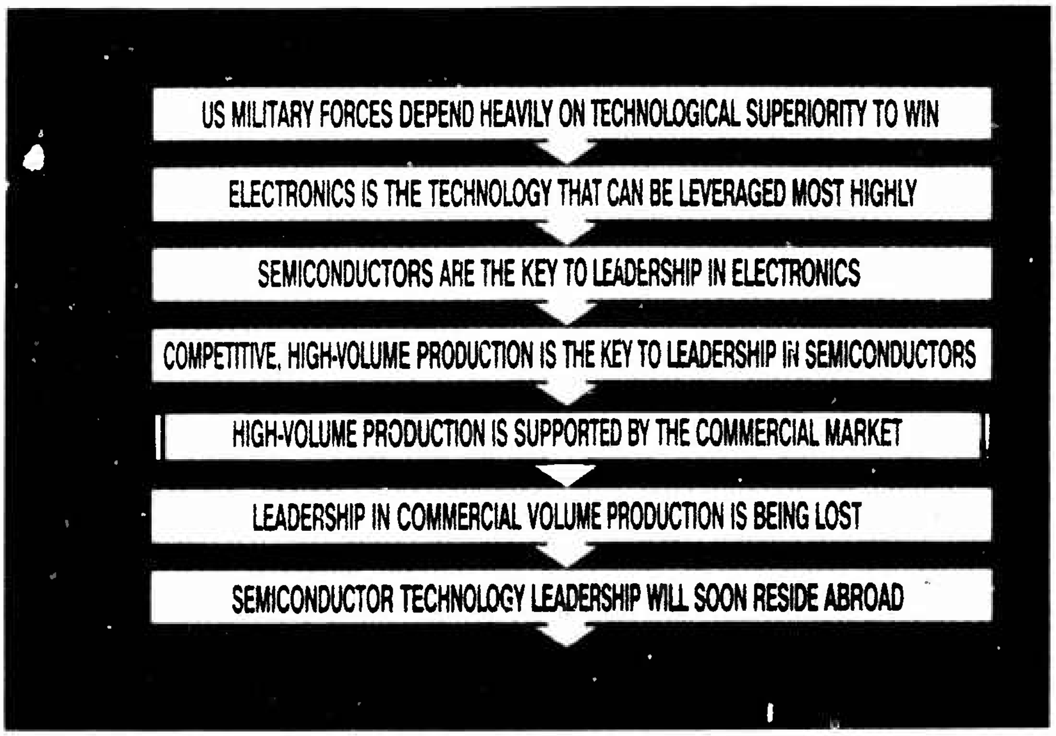


FIGURE 38.

High-volume production is supported by the commercial market.

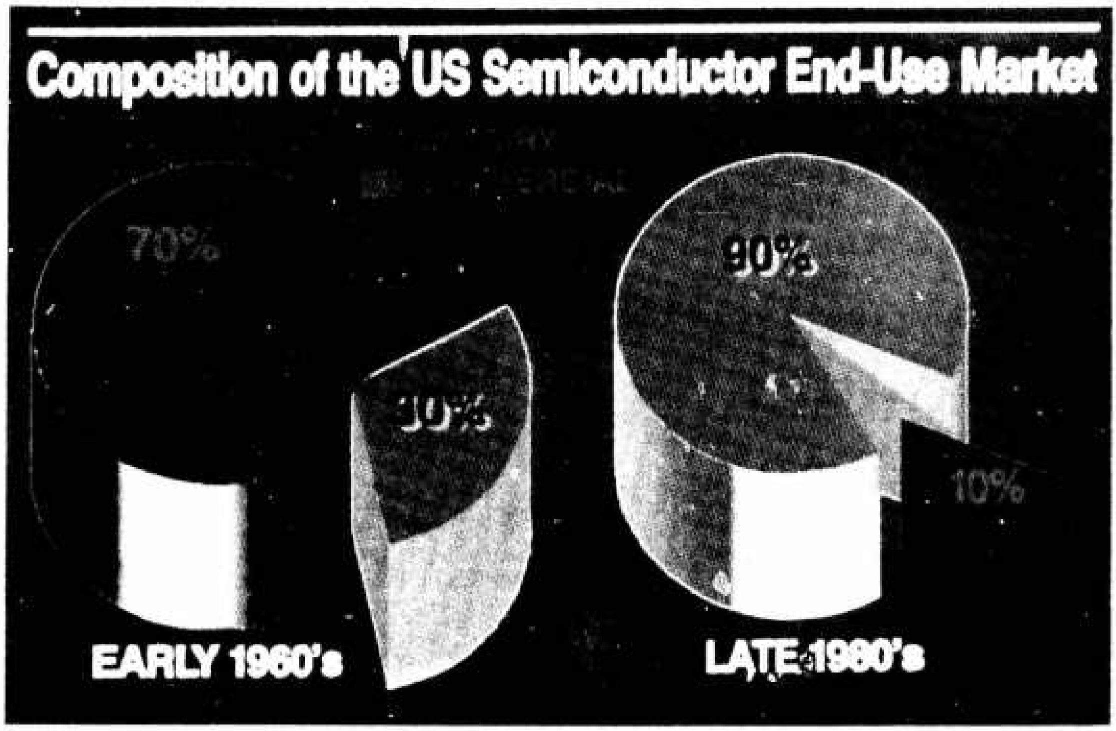


FIGURE 39.

A major asymmetry exists in the interdependency between national defense needs and the needs of the semiconductor industry. In the 1960's, the military was a dominant procurer of semiconductors in the United States. Today the U.S. military acquires less than ten percent of the output of the merchant semiconductor industry. Thus, although semiconductors are of enormous importance to the Defense Department, the Defense Department is not today of enormous importance to the semiconductor industry. This is a fundamental factor underlying the recommendations which will follow.

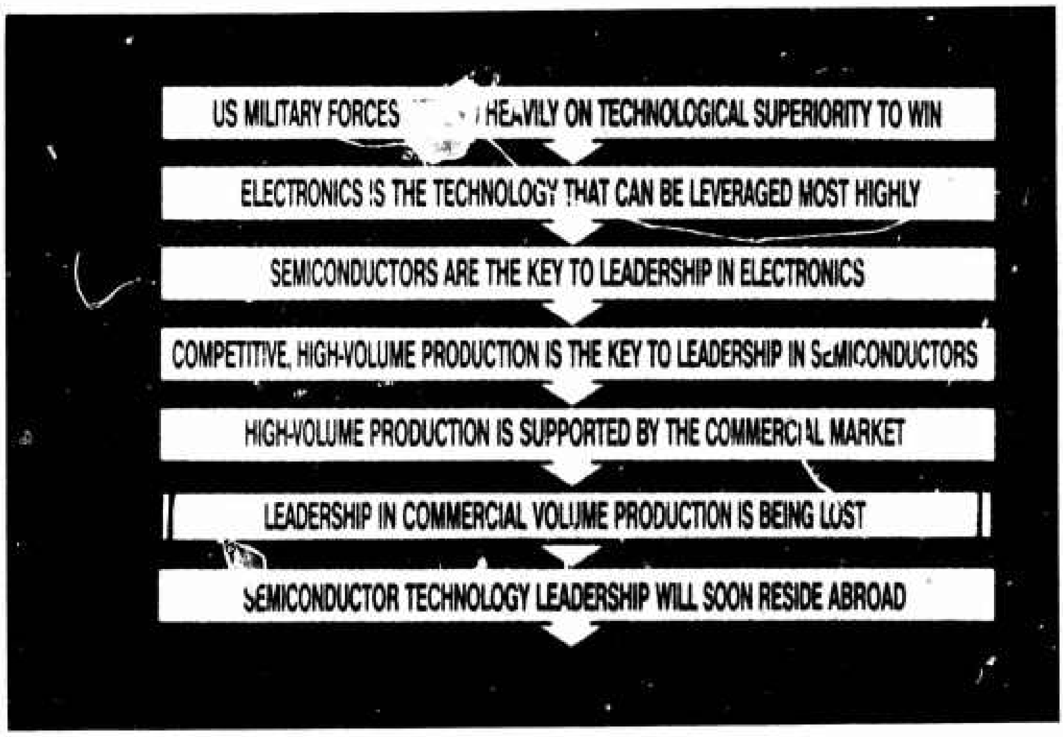


FIGURE 40.

Leadership in commercial volume production is being lost by the U.S. semiconductor industry.

Semiconductor Industry Rankings
(by Sales Volume)

1975	1980	1986 (EST.)
TEXAS INSTRUMENTS	TEXAS INSTRUMENTS	NEC
FAIRCHILD	MOTOROLA	HITACHI
NATIONAL	PHILIPS	TOSHIBA
MOTOROLA	NEC	TEXAS INSTRUMENTS
PHILIPS	NATIONAL	MOTOROLA
INTEL	TOSHIBA	FUJITSU
	HITACHI	PHILIPS
	INTEL	INTEL
	FAIRCHILD	MATSUSHITA
	SIEMENS	NATIONAL

FIGURE 41.

U.S. firms, which generally dominated the semiconductor market as recently as in 1975, today suffer continuing deterioration in market position. Semiconductor firms can generally be categorized into two groups: 1) "merchant" manufacturers (which provide integrated circuits for incorporation into the products of others), and 2) "captive" producers (such as IBM and AT&T which produce principally for their own end-use products). Defense Department prime contractors are generally dependent upon the merchant industry for the semiconductors which are incorporated into the systems they produce. The ranking shown in the figure for 1986 is based upon industry estimates. As recently as 1985, U.S. firms held the number 2, 3, 8 and 9 positions.

Number of Firms Engaged in Commercial Production of Dynamic RAMS

YEAR	[illegible]	No. OF US FIRMS	No. OF JAPANESE FIRMS
1970	[illegible]	14	8
1974	[illegible]	15	6
1978	[illegible]	12	6
1982	[illegible]	5	6
1985	[illegible]	3	7
1986	[illegible]	3	7

FIGURE 42.

As the position of U.S. semiconductor suppliers in the world marketplace has deteriorated in terms of total volume of production, so too has the number of firms capable of producing the most advanced generation of devices at any given time. Of the three U.S. firms now making one megabit Dynamic Random Access Memory chips, two are captive firms producing principally for their own (essentially commercial) consumption.

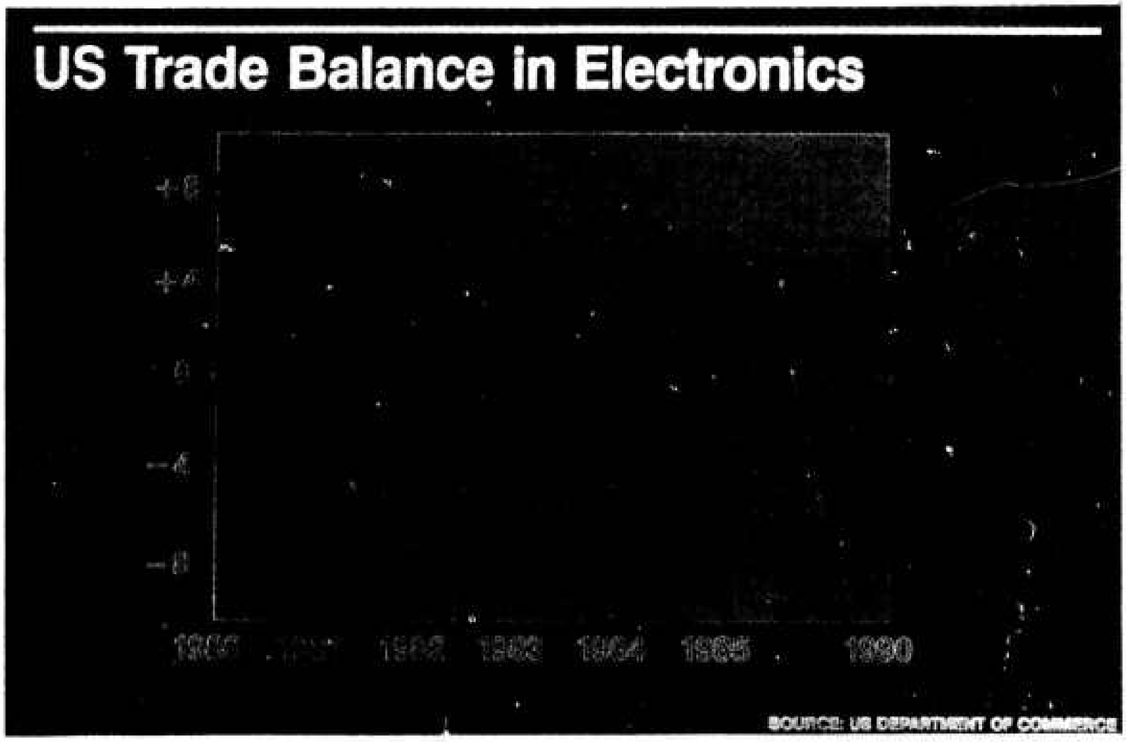


FIGURE 43.

The overall U.S. trade balance in electronics reflects the circumstances described in the previous charts for semiconductors. Over a period of approximately five years, the nation has seen its trade position in electronics shift from one of an $8 billion surplus to one of an $8 billion deficit. Nearly $2.5 billion of this deficit can be attributed specifically to semiconductor chip trade with Japan.

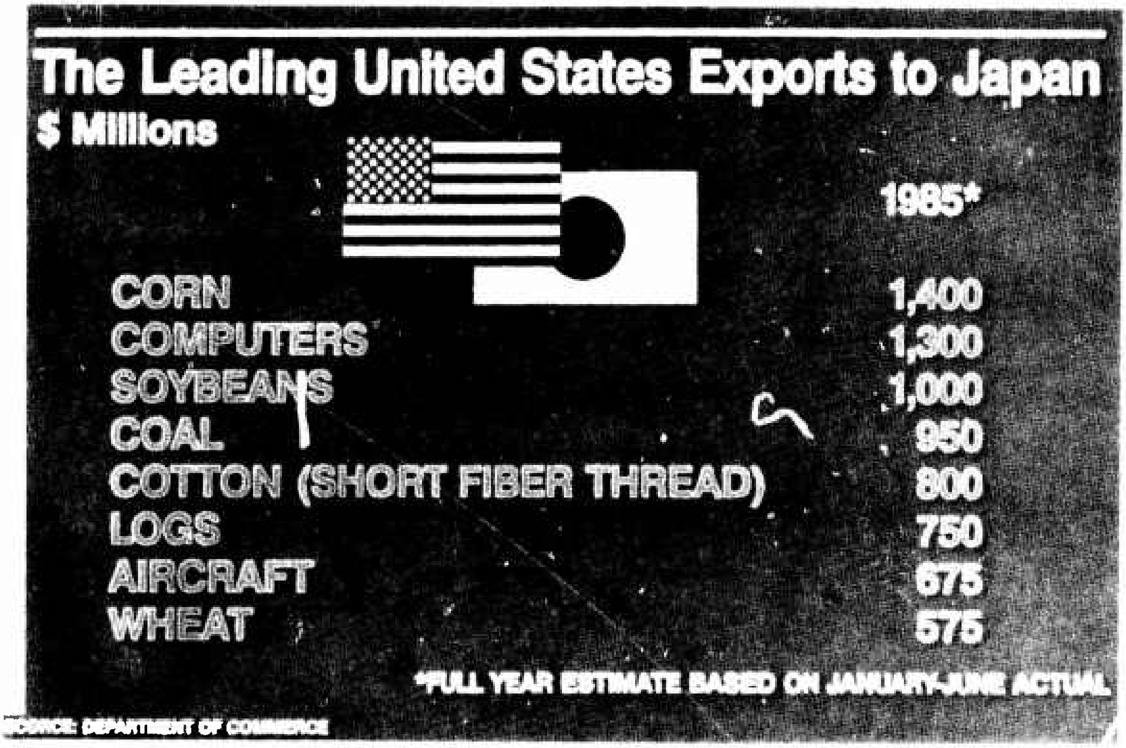


FIGURE 44.

A list of the leading United States exports to Japan raises concerns over the posture of the United States as a modern industrial competitor. Of the list shown, only computers and aircraft contain significant technological value-added. It may well be possible to build a viable economy based on service (and raw material) industries, but it is highly unlikely that it is possible to fight and win wars with a service economy.

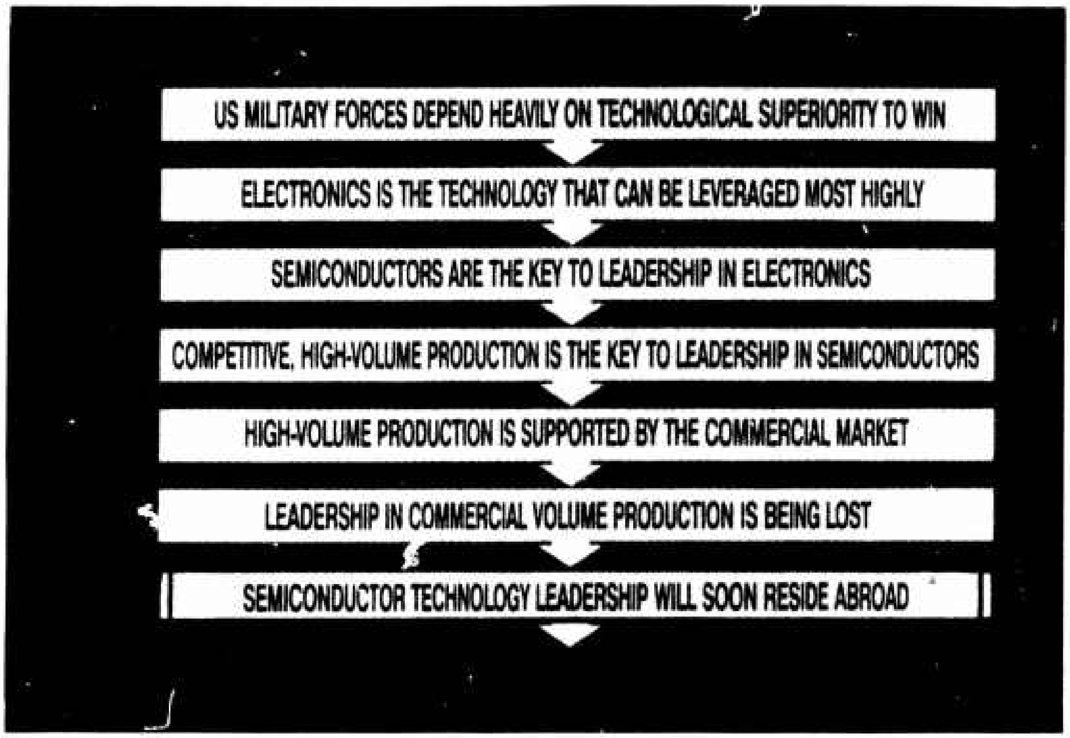


FIGURE 45.

Semiconductor technology leadership will soon reside abroad.

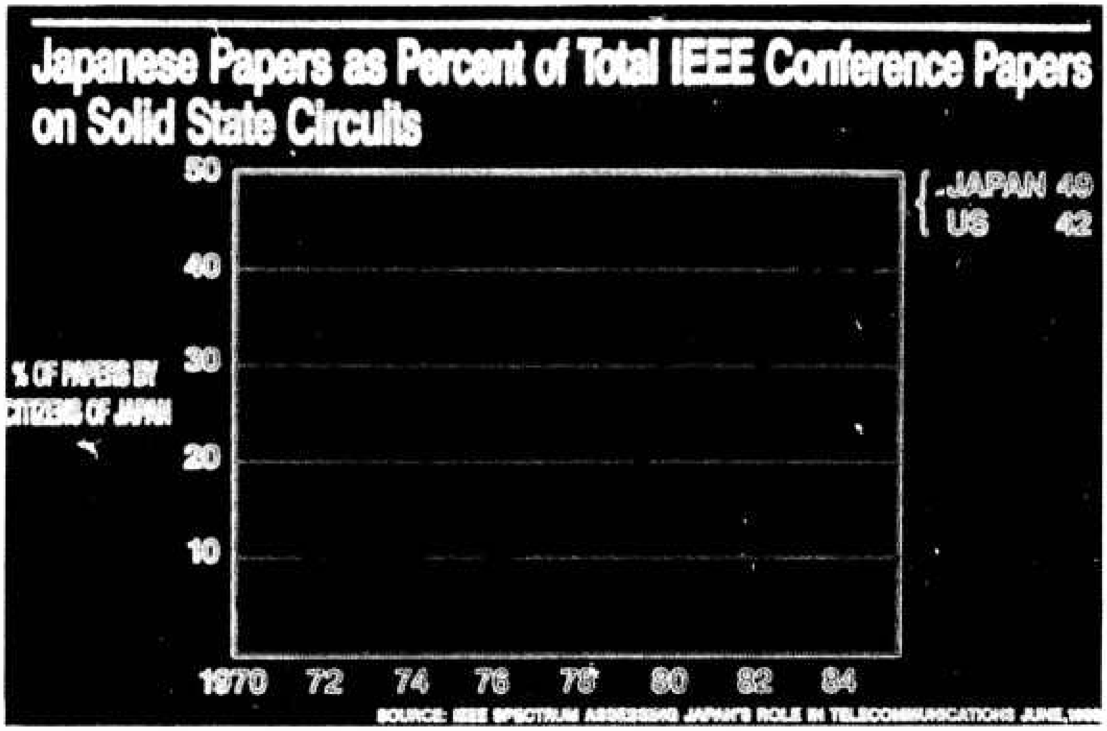


FIGURE 46.

As the leading edge of manufacturing technology has moved abroad from the United States, so too has much of the technology which underpins that manufacturing capability. As has already been noted, manufacturing technology is the underpinning of the ability of the semiconductor industry to compete in the world market. In the U.S. economic structure, manufacturing provides the revenues for firms to support research and development. Additionally, in the case of semiconductors, much of the critical technology itself resides in the manufacturing process. Perhaps the best indicator of the trend toward technological leadership by Japan is the number of papers presented each year describing key advancements in the state-of-the art of solid state circuitry. In 1985, for the first time, Japanese citizens surpassed U.S. citizens in terms of the number of papers selected for presentation at the premier forum for describing such advancements, the Institute of Electrical and Electronic Engineers' conference on solid state circuits. One important related area in which the U.S. is continuing to maintain a position of prominence is software.

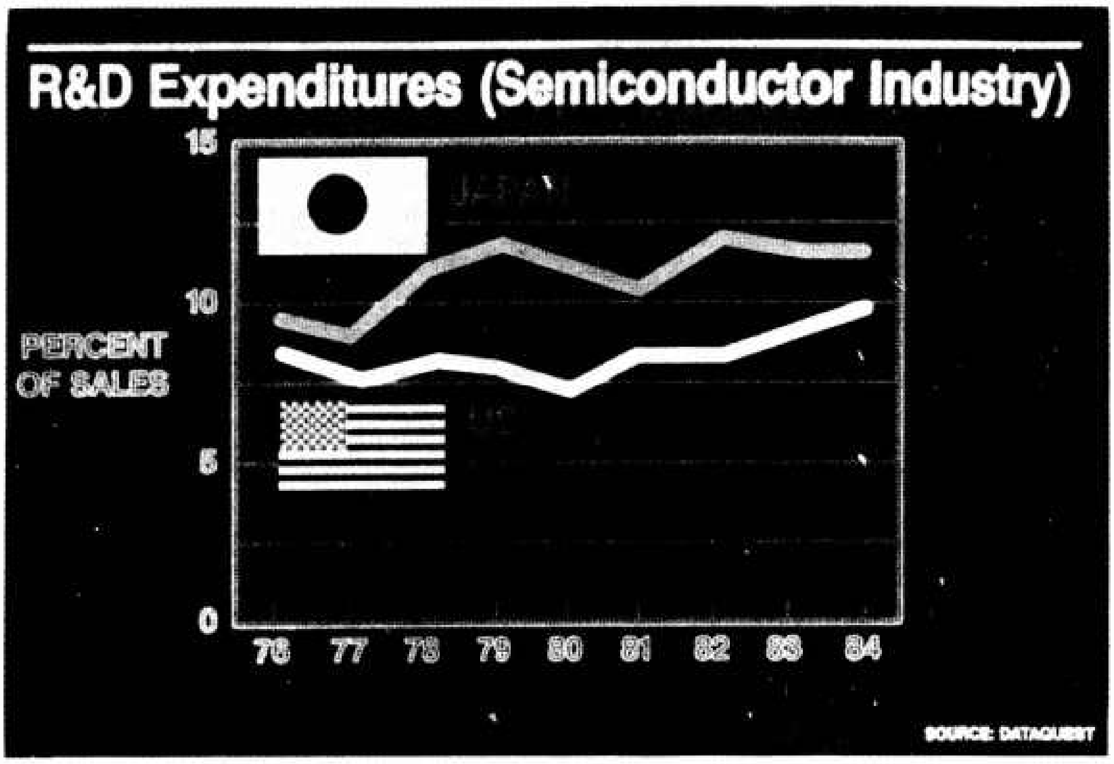


FIGURE 47.

For a number of years, Japan has been expending a greater portion of its semiconductor sales volume on research and development than has the United States. The impact of this long-term practice is today being exacerbated as the absolute size of Japanese semiconductor sales increases relative to those of American producers. Today, Japan is spending about 10 percent more on semiconductor research and development than the U.S. A recent National Research Council study concluded that of ten key technologies relating to microelectronics, Japan leads in seven. As will be addressed subsequently, the Japanese program tends to be more efficient than that of U.S. firms because of the elimination of duplicate generic research.

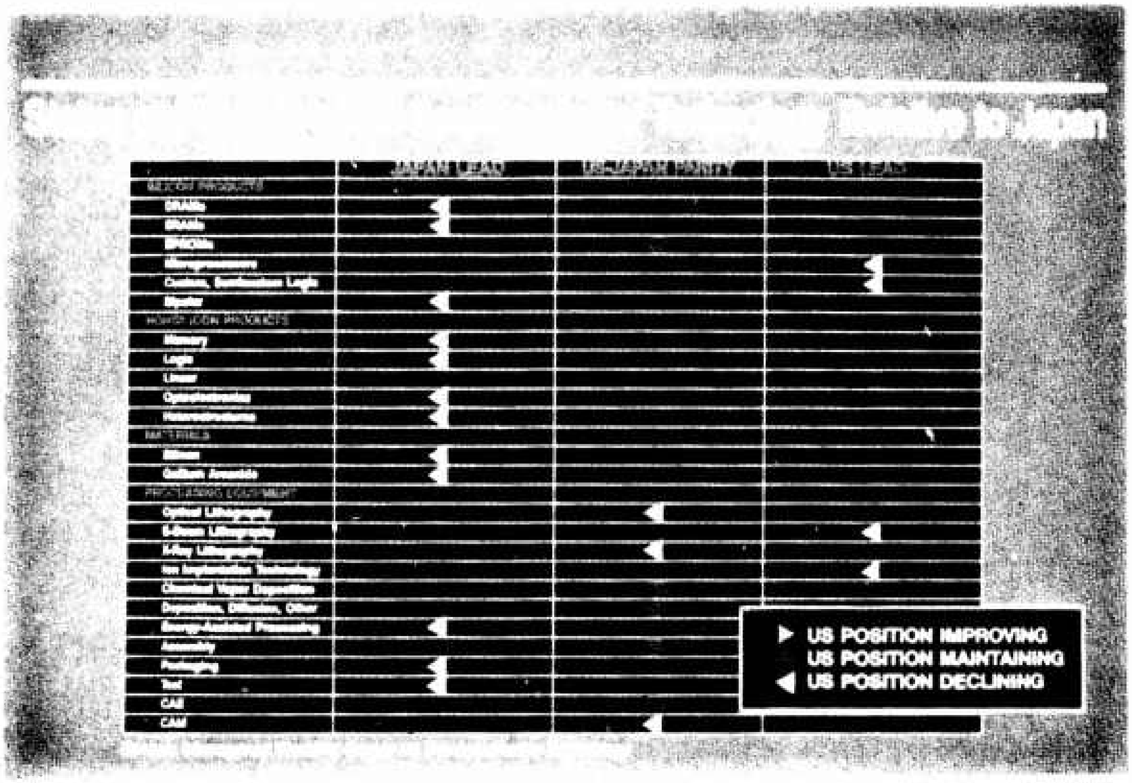


FIGURE 48.

Although highly subjective and undoubtedly subject to debate in its particulars, one recent study conducted by the U.S. government's Interagency Working Group on Semiconductor Technology reveals an unmistakable trend in terms of leadership relating to key semiconductor technologies.

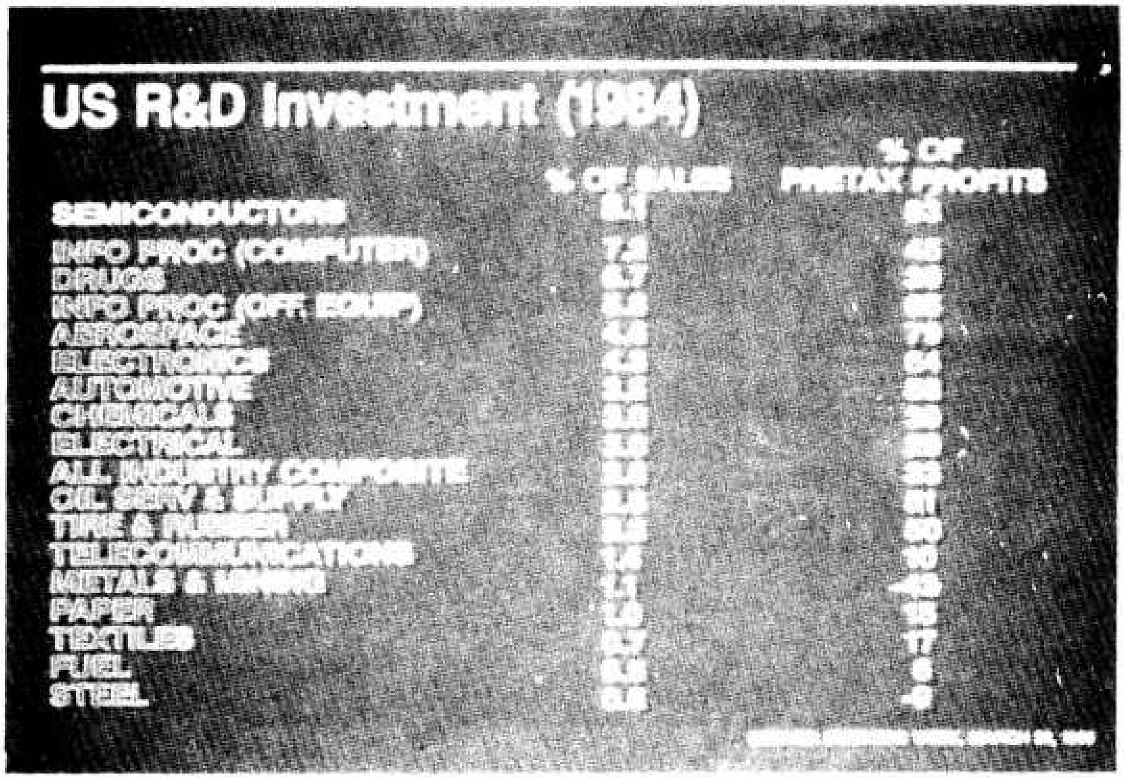


FIGURE 49.

The adverse trend in R&D expenditures of the U.S. semiconductor industry in comparison with those of Japanese counterparts is not principally explainable in terms of neglect of R&D by the American industry -- at least using conventional U.S. investment standards. The U.S. semiconductor industry leads all other principal U.S. industries in terms of its reinvestment in R&D. The problem is that this has simply been insufficient by worldwide standards.

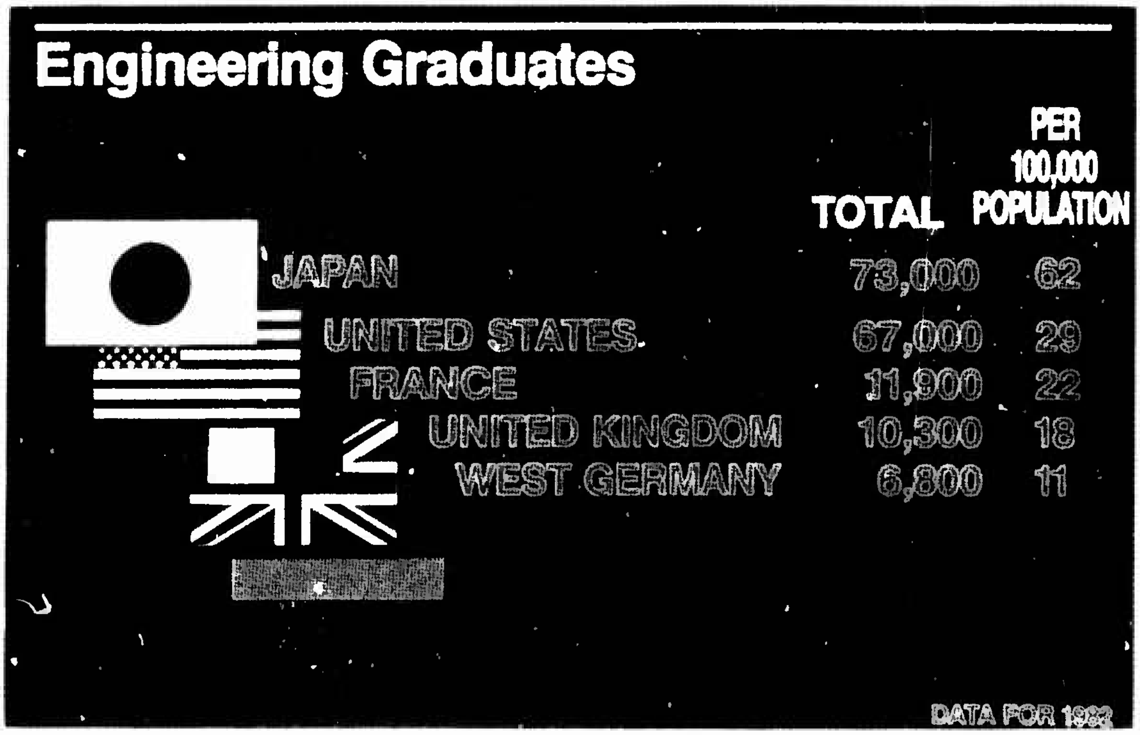


FIGURE 50.

Japan's focus on technology and R&D is reflected in its rate of graduation of engineers which currently surpasses that of the United States on a per capita basis by a factor of two. In terms of Electrical Engineering graduates, Japan produces about 30% more than the U.S. in absolute terms. Science and Engineering enrollment in U.S. graduate schools is today about half non-U.S. citizens. Graduates of Japanese universities frequently seek positions in manufacturing-related disciplines -- whereas in the U.S., manufacturing has often been viewed as a less attractive professional pursuit than such fields as finance, marketing, management, etc. The quality of U.S. engineering education continues, in general, to be excellent -- particularly as it relates to innovation.

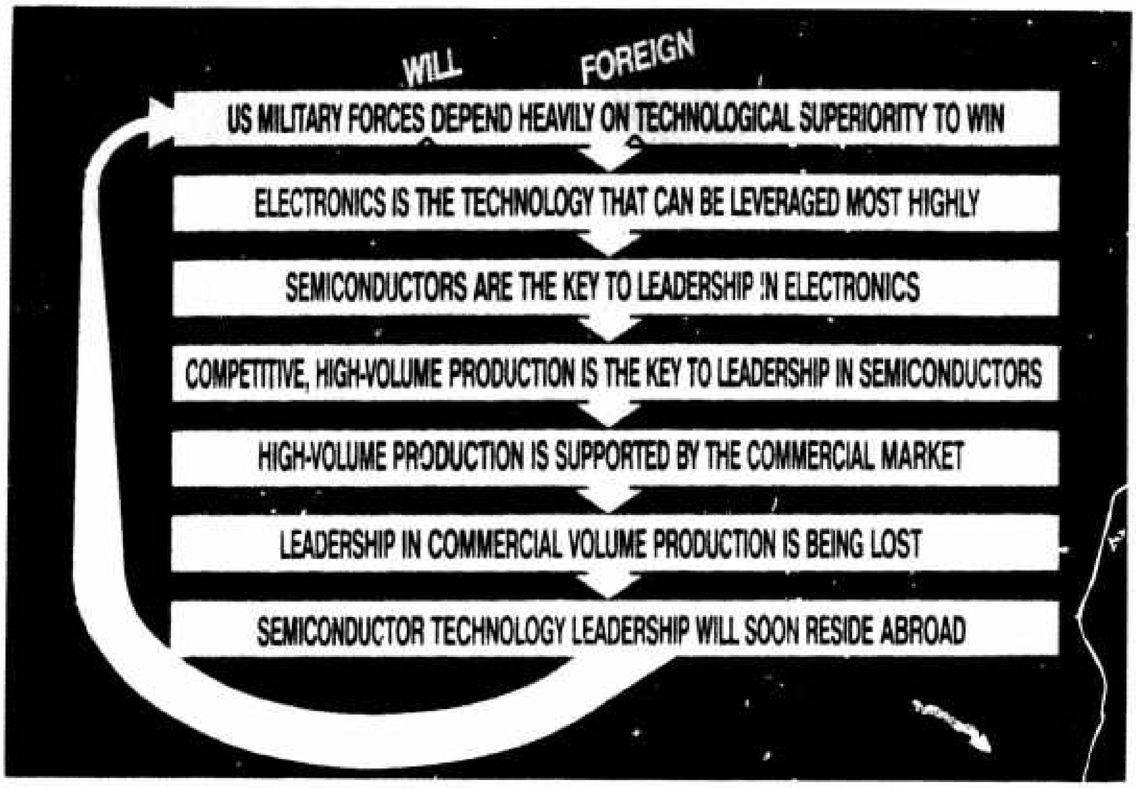


FIGURE 51.

U.S. military forces will depend heavily on FOREIGN technological superiority to win (unless significant steps are taken soon to reverse the present trend).

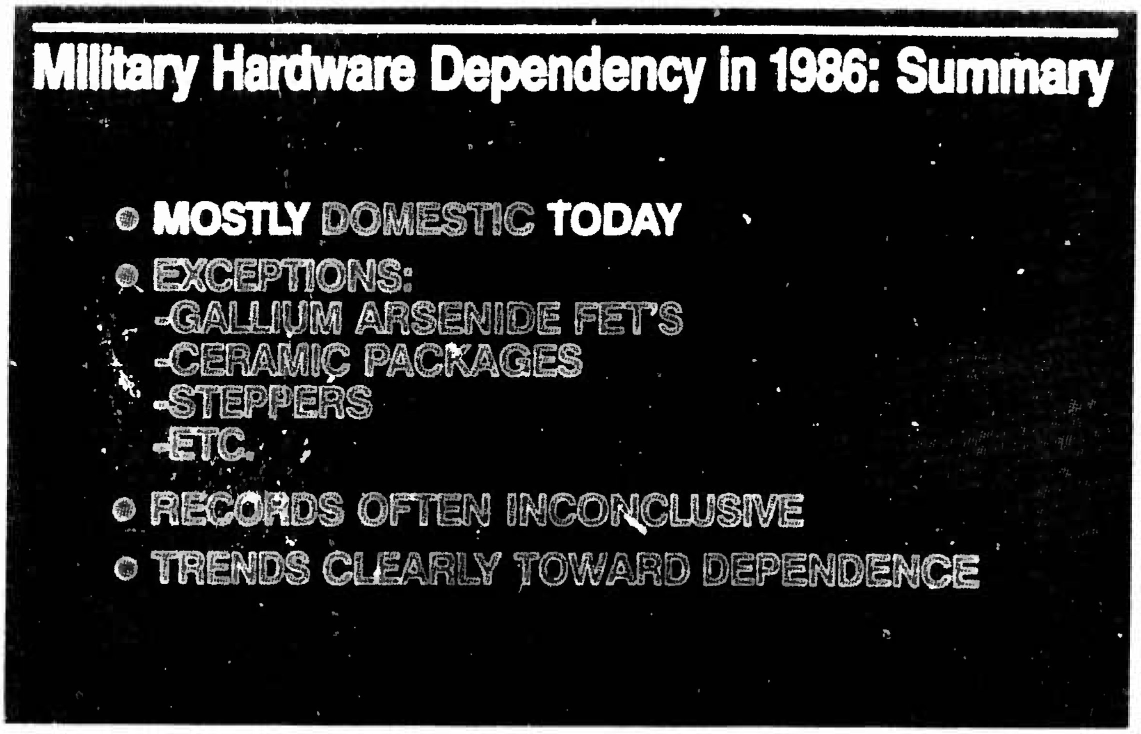
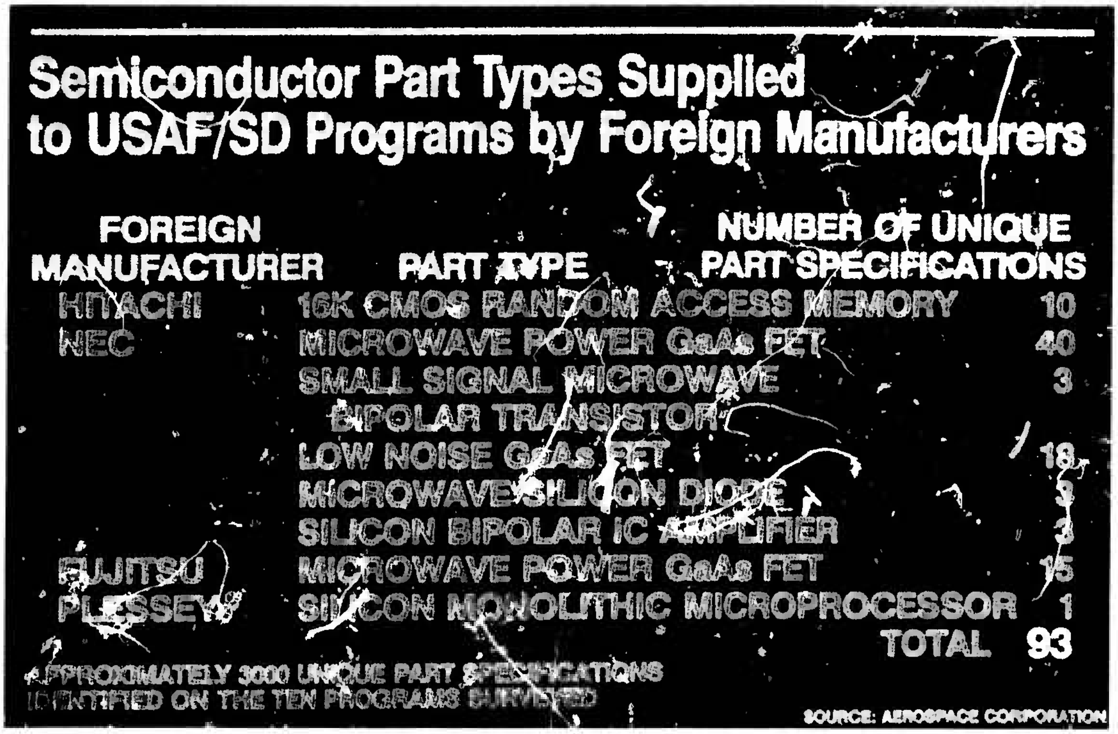


FIGURE 52.

Although important examples can be found where U.S. military forces are today dependent upon electronic hardware built overseas by foreign producers, the extent of the former practice is considerably less than had been projected by many industrial experts. In retrospect, it appears that such a result should have been expected inasmuch as most of the hardware incorporated in today's production and operational military systems had its design origin in the 1970's and early 1980's, at which time the U.S. still held a dominant position in semiconductor manufacturing. It would appear that in the 1990's an opposite conclusion will result if steps are not now taken to reverse the trends observed herein. Even today there are important areas of dependency, including field effect transistors, ceramic packages (available from virtually a single producer in the world -- a firm in Japan) and precision alignment manufacturing equipment. A National Academy of Engineering Study recently concluded that in the case of one missile system it would take over a year to replace foreign parts content (of all types) with domestically supplied hardware. To preclude the expansion of this circumstance, government program offices need to ascertain the origin of the components incorporated in their systems and assure the existence of viable domestic sources in time of emergency -- or else maintain suitable stockpiles.


Semiconductor Part Types Supplied to USAF/SD Programs by Foreign Manufacturers

FOREIGN MANUFACTURER	PART TYPE	NUMBER OF UNIQUE PART SPECIFICATIONS
HITACHI	16K CMOS RANDOM ACCESS MEMORY	10
NEC	MICROWAVE POWER GaAs FET	40
	SMALL SIGNAL MICROWAVE BIPOLAR TRANSISTOR	3
	LOW NOISE GaAs FET	18
	MICROWAVE SILICON DIODE	3
	SILICON BIPOLAR IC AMPLIFIER	3
FUJITSU	MICROWAVE POWER GaAs FET	15
PLESSEY	SILICON MONOLITHIC MICROPROCESSOR	1
	TOTAL	93

APPROXIMATELY 3000 UNIQUE PART SPECIFICATIONS IDENTIFIED ON THE TEN PROGRAMS SURVEYED

SOURCE: AEROSPACE CORPORATION

FIGURE 53.

In one survey conducted by the Aerospace Corporation of ten Air Force systems produced by the Space Division, only about three percent of the semiconductor devices (as measured by parts specifications) were of foreign origin. Some of these, however, were critical to the operation of the systems in question and the trend toward foreign content would appear to be growing. Further, most program offices do not keep records of dependency beyond the country-of-origin label on a finished device, even though dependency is at issue at every level (materials, tools, packaging, testing, etc.) of the semiconductor industry infrastructure.

FIGURE 54.

A number of examples were found in a study conducted for the Task Force by the Institute for Defense Analyses of systems containing semiconductors available only from foreign-owned, foreign-located sources. Even many of the "so-called" domestic semiconductor devices incorporated in U.S. military systems can be traced to foreign countries in terms of the raw materials and processes involved in their manufacture -- the latter including packaging and testing. A large share of integrated circuits are assembled and tested overseas. Ceramic packages are available almost exclusively from Japan -- in this case from a single firm. One government sponsored study of Foreign ependency identified 16 components of foreign source in one current air-to-air missile and concluded their denial would shut down production for up to 18 months. In addition, a growing segment of the semiconductor manufacturing capacity which resides in this country is being acquired by foreign firms through outright purchase.

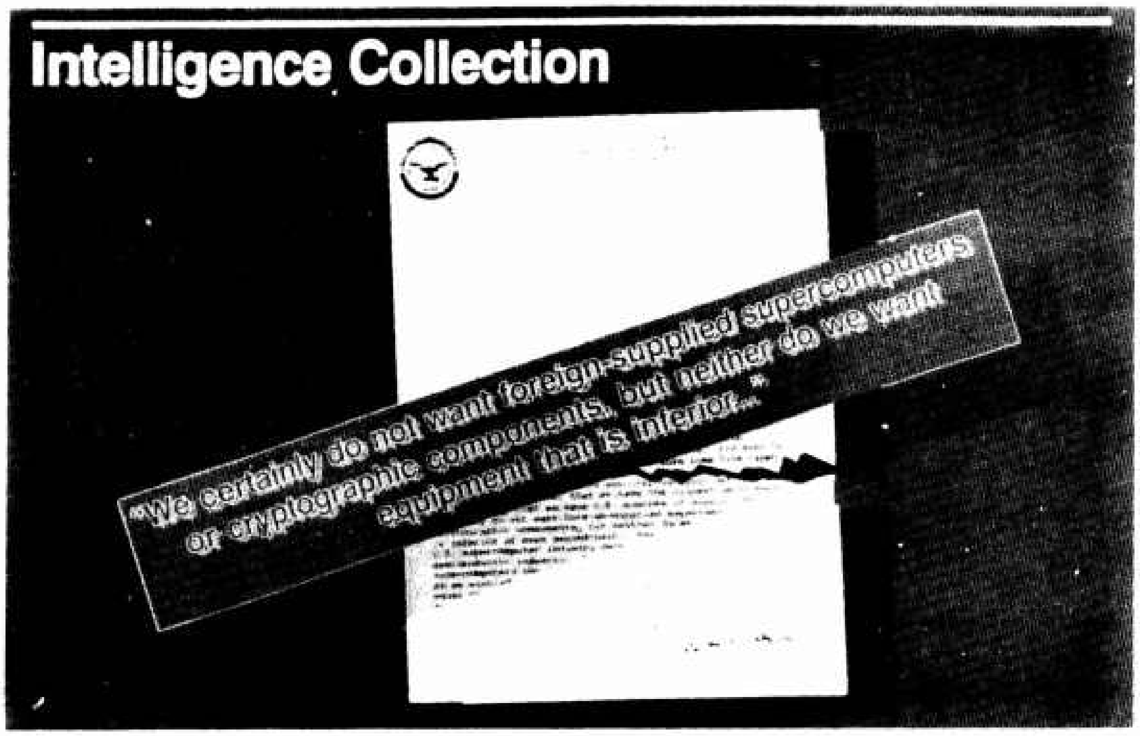


FIGURE 55.

Command, control, communications and intelligence systems are particularly dependent upon the availability of the most advanced semiconductor devices. In the area of cryptography, for example, the ability to protect one's communications and to collect intelligence from others resides to a very great extent on the possession of the most advanced generation of supercomputer.

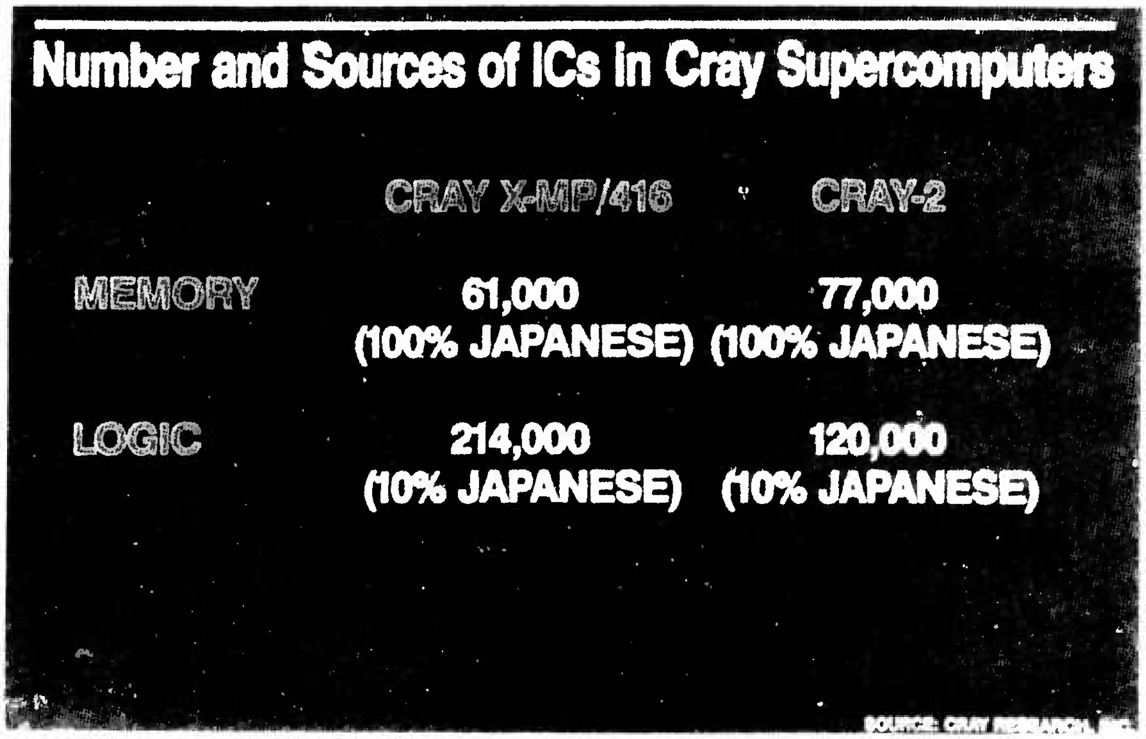


FIGURE 56.

Among the most advanced supercomputers produced in the United States are those manufactured by Cray Research, Inc. These machines are particularly important to many military command and intelligence functions. Today, 100 percent of the memory capacity of these machines is derived from Japanese manufactured semiconductors, and ten percent of the logic elements are of corresponding origin. As Japanese firms evolve from the role of merchant semiconductor manufacturers into computer/telecommunications system builders, it would not be an illogical strategic business policy to delay release of the most advanced chips to competitors in the systems market, including those residing in the United States. Even if foreign manufactured chips are to be available to U.S. manufacturers, it would appear likely that these chips will be a generation behind those which foreign semiconductor manufacturers elect to incorporate in their own system-level products. That is, today's foreign semiconductor suppliers to U.S. firms may become tomorrow's competitors to those same U.S. firms for system products.

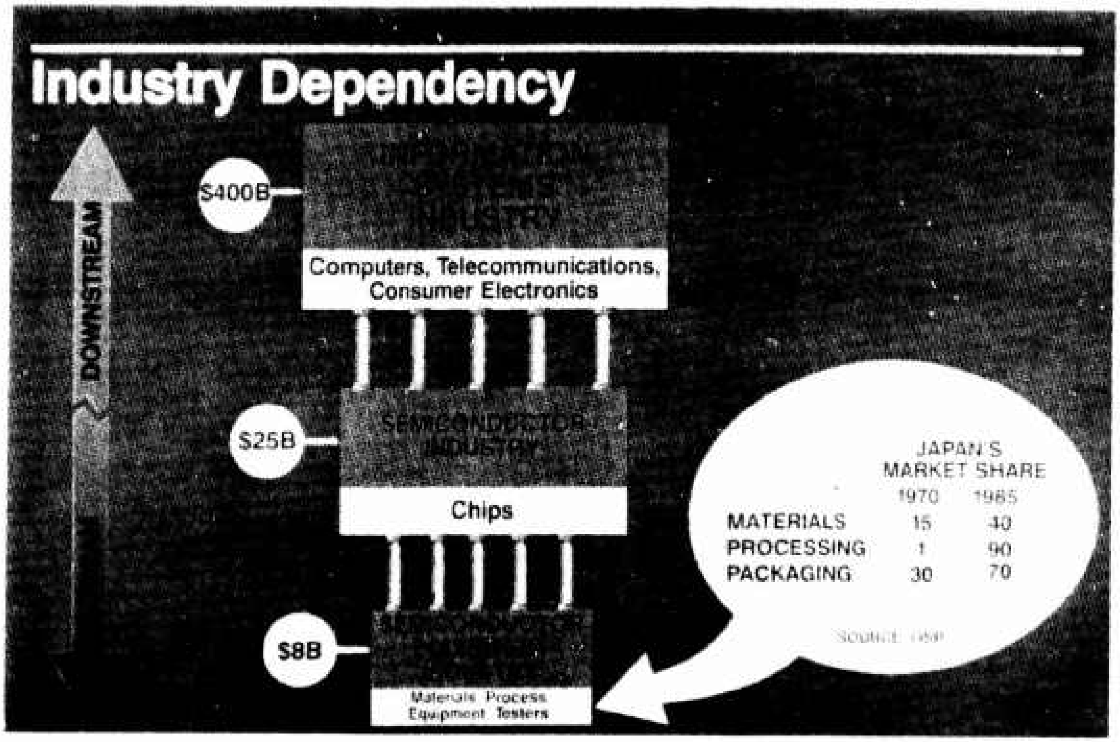


FIGURE 57.

The United States semiconductor industry is dependent upon several related "upstream" industries such as the producers of materials and the developers of the equipment needed to manufacture in high volume. These latter firms, generally referred to as "equipment" suppliers, to a considerable degree help determine the competitive state-of-the-art of U.S. semiconductor manufacturers. The U.S. equipment industry has itself been moving off-shore and today many, if not most, of the advanced production capabilities are acquirable only overseas. Delays in access to the most advanced equipment measured even in months can in essence pace the U.S.'s ability to introduce future generations of semiconductor devices and the systems they in turn support. Importantly, this dilemma confronts not only the U.S. merchant industry but the large captive firms as well, since it is very difficult for even this latter group to support an entire equipment industry and at the same time remain price competitive in the world market for their own products. The semiconductor equipment industry in many respects provides the second-tier underpinning of the enormous world-wide information systems industry.

FIGURE 58.

Although the Task Force initially focused on the availability of semiconductor hardware to support defense needs, particularly during time of mobilization, it rapidly became evident that the principal concern was the fact that advanced semiconductor technology simply would not be available within the United States to support the development of leading edge defense systems.

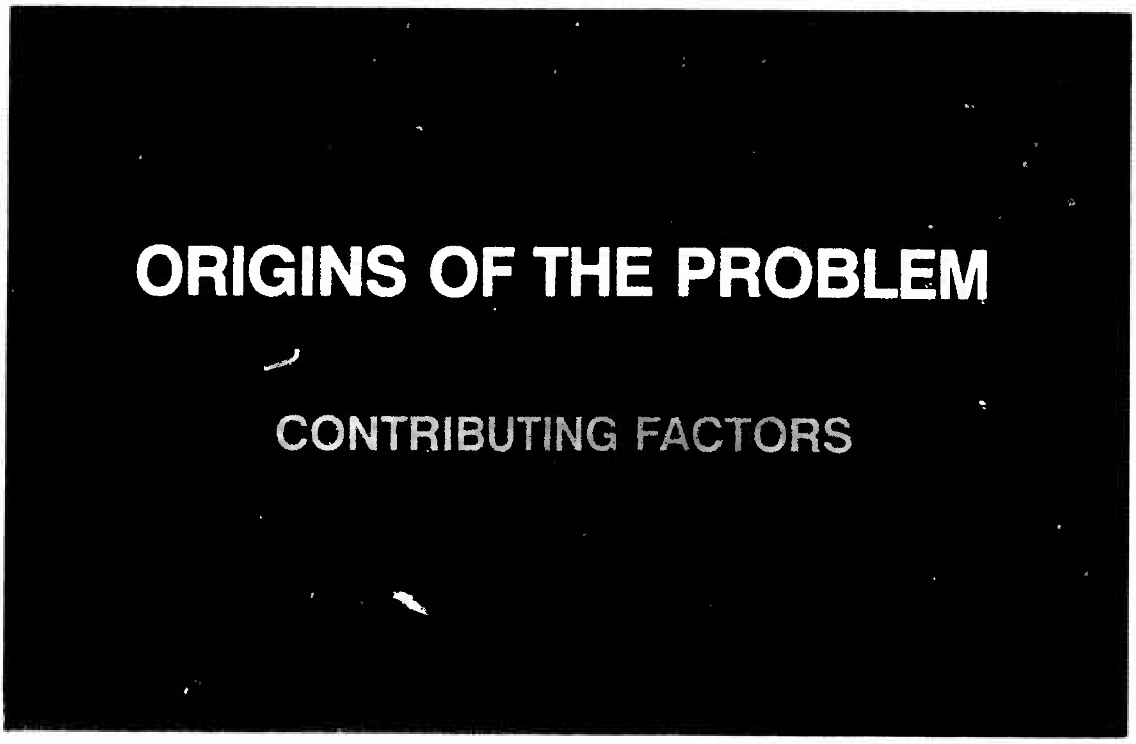


FIGURE 59.

The Task Force has identified at least a dozen not insignificant factors which have contributed to the decline of the U.S. semiconductor industry. Some of these factors were within the control of the industry; many were not. Correspondingly, there is no single action which by itself is likely to resolve the current predicament in which the U.S. finds itself with respect to assuring a domestic supply of advanced integrated circuits.

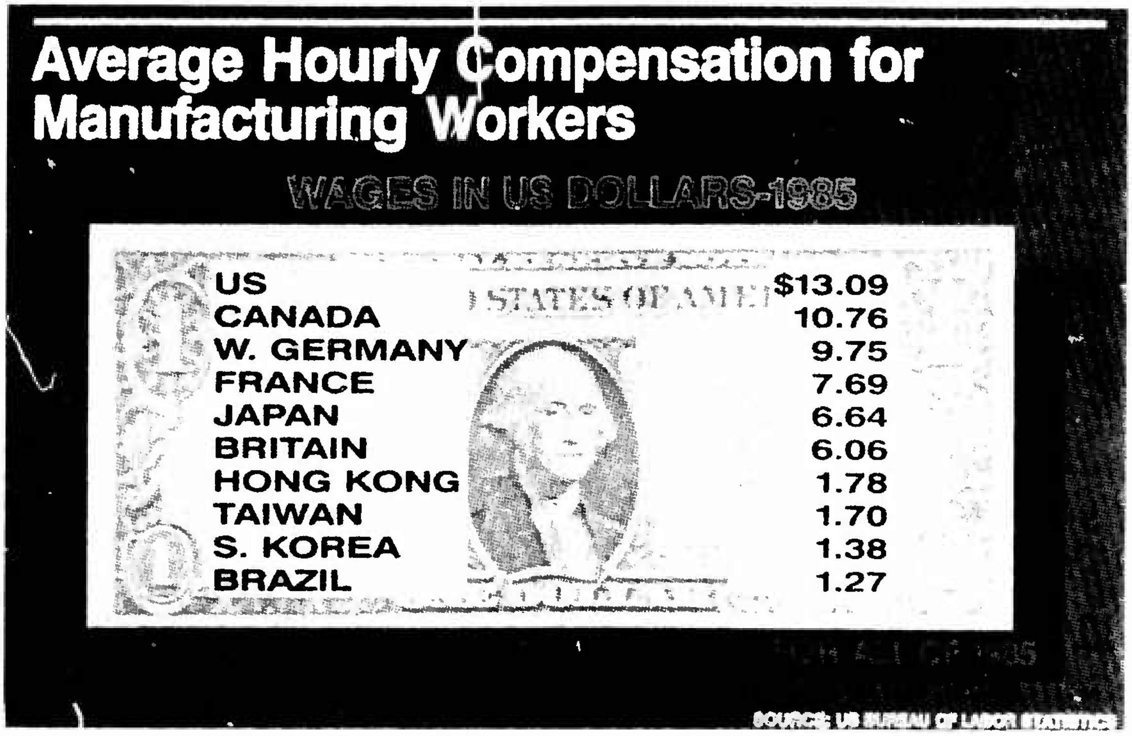


FIGURE 60.

The current posture of the U.S. semiconductor industry can be traced to many origins. In the early years, wages for manufacturing workers in the United States were significantly greater than those for their counterparts in the Pacific rim. In order to remain competitive in the world market, U.S. manufacturers themselves moved facilities to Japan, Korea, Taiwan, Hong Kong and Malaysia in order to avail themselves of the labor forces available in those areas. As wage rates have recently become more commensurate and the semiconductor industry has become increasingly automated, the impact of geographical wage differences has approached insignificance.

FIGURE 61.

The concentration of nations such as Japan and Korea on productivity and quality throughout their entire industrial base began to take its toll on the U.S. semiconductor industry, along with other U.S. industries, in the 1970's. The productivity challenge was particularly acute among semiconductor manufacturers due to the need to re-automate factories as new generations of products were introduced every few years. In general, the productivity record of the U.S. semiconductor producers far exceeded that of U.S. industry as a whole. Correspondingly, problems with quality among U.S. producers during the 1970's contributed to the current adverse situation and are still cited by Japanese buyers as a reason for not purchasing U.S. manufactured devices.

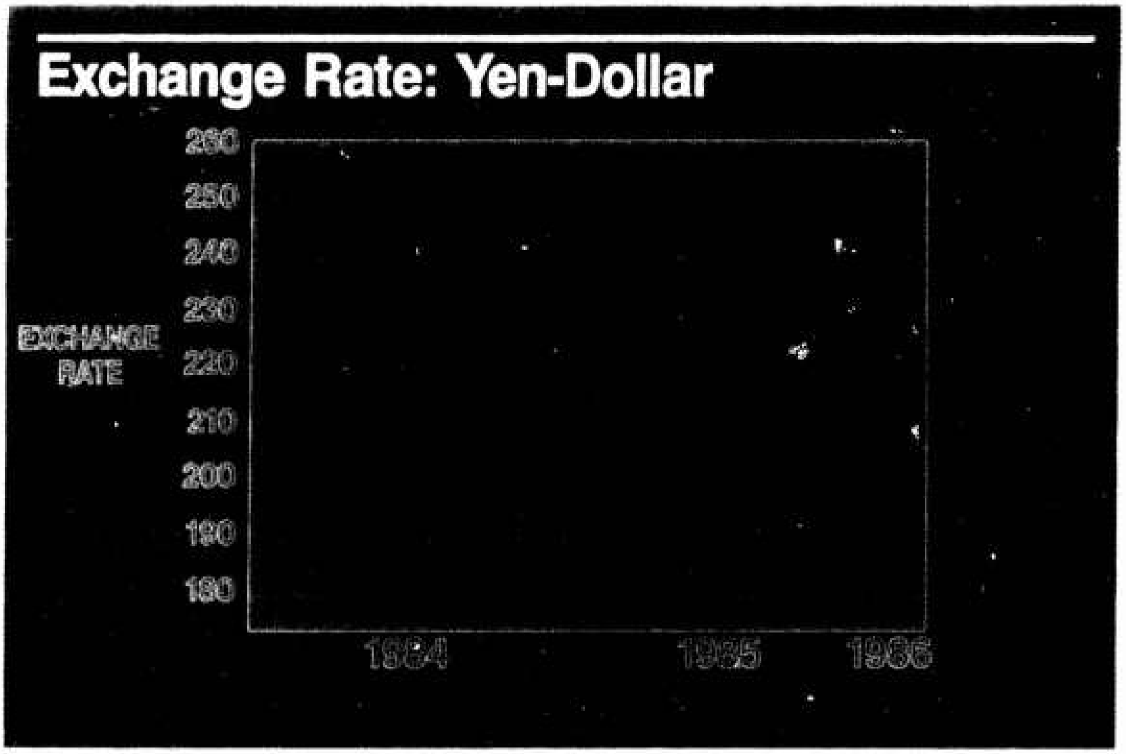


FIGURE 62.

During the 1980's, the high yen/dollar exchange rate which persisted for a number of years further undermined the ability of U.S. semiconductor producers to compete in the world market. Trends during the last few months have, however, greatly offset this factor as a contributor to further decline in U.S. semiconductor manufacturing.

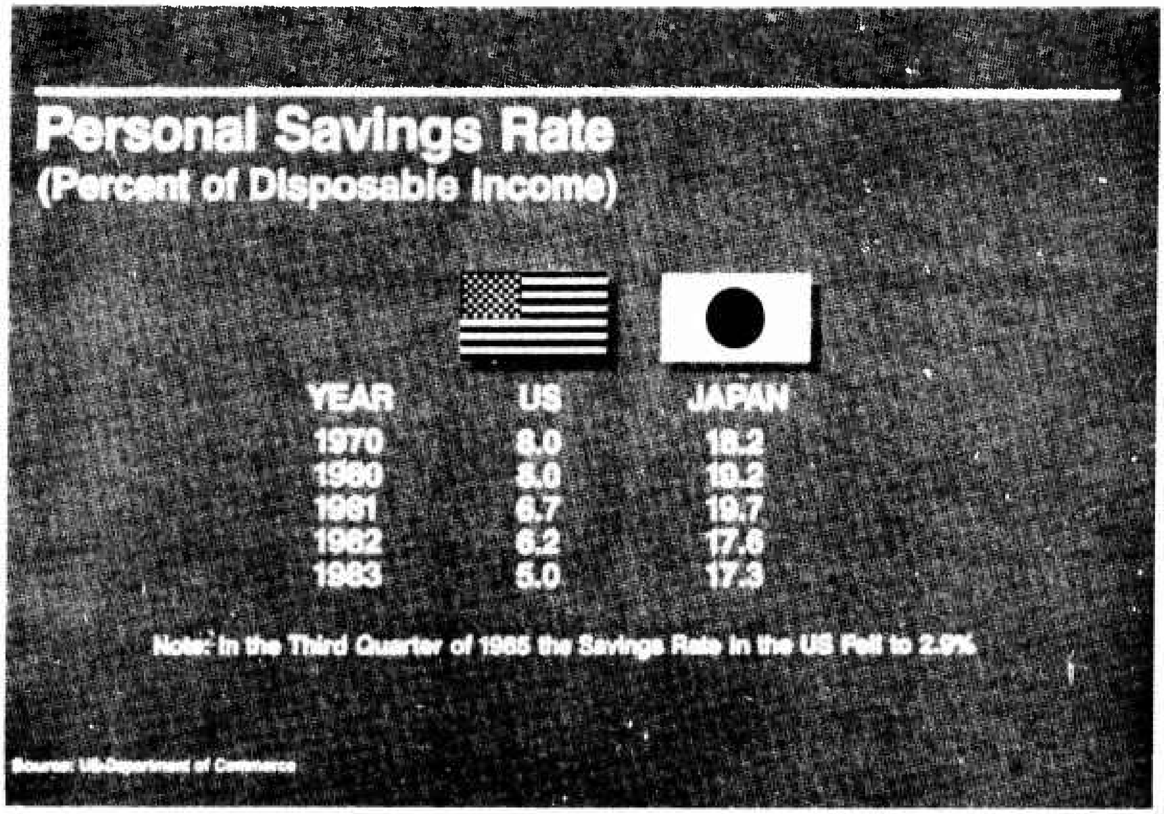


FIGURE 63.

The relatively high cost of capital to U.S. industrial firms as compared with their Japanese counterparts exacerbated the problem of funding research and development and equipment in the U.S. This asymmetry has origins deeply rooted in the economic structures of the two nations in such areas as disparity of savings practices and tax incentives. In the former instance, for example, the personal savings rate in Japan is about three times that of the U.S. (5% vs. more than 15%).

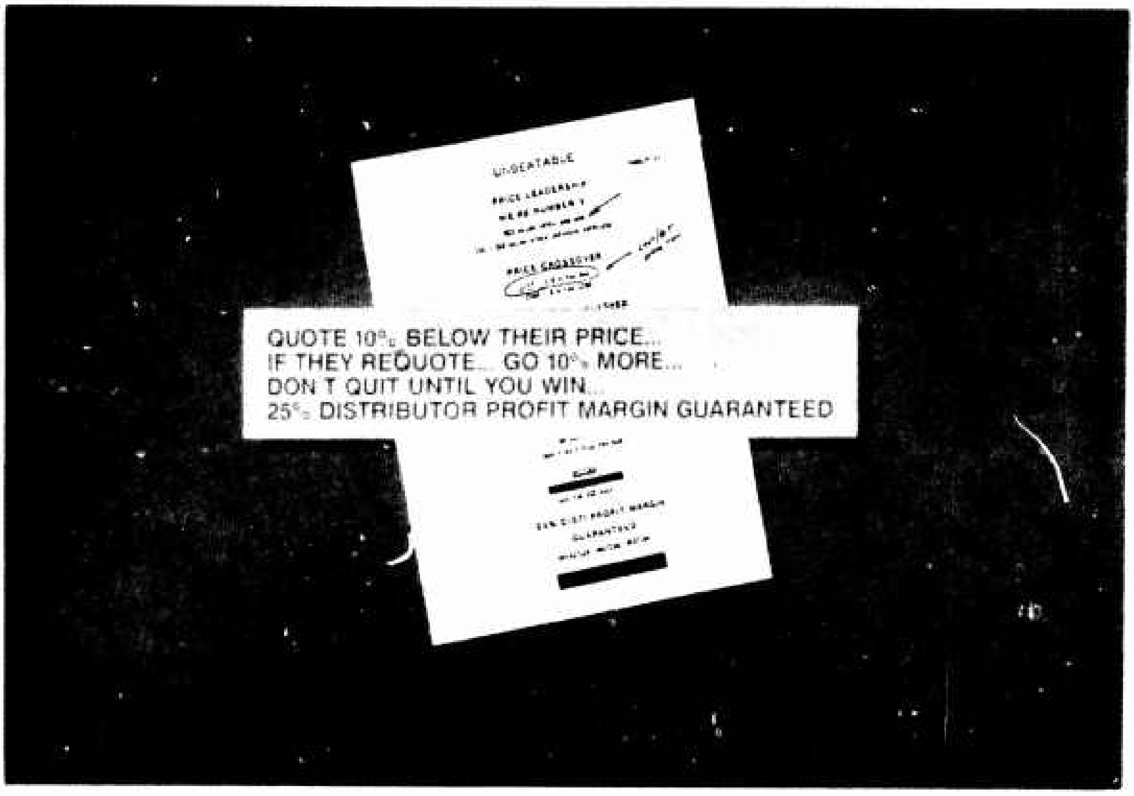


FIGURE 64.

"Dumping" by foreign semiconductor producers is widely cited as a principal cause of the deteriorating viability of the U.S. semiconductor manufacturing industry. Although evidence of such practices certainly appears to exist, this practice can be viewed as but one of a number of adverse factors and, in the view of this Task Force, is probably not the predominant one.

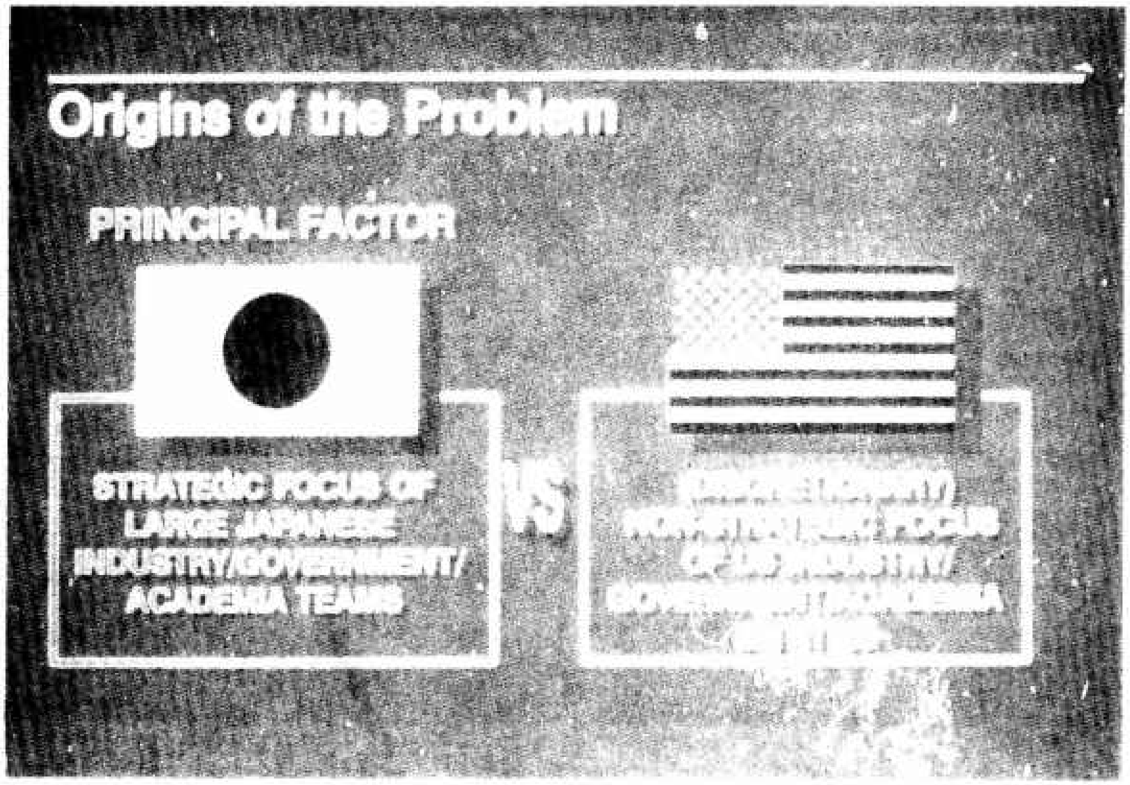


FIGURE 65.

In the opinion of the Task Force, the principal factor affecting the relative shift in strength of the U.S. and Japanese semiconductor industries is the fact that the Japanese established a <u>strategic (long term) goal</u> and effectively brought together all the <u>resources</u> needed from government, industry and academia, needed to pursue that goal. The U.S., <u>at its own discretion</u>, elected not to pursue such an organized focus and structure, and as a result is finding that it is unable to compete in the marketplace as it has been defined by the Japanese. Although this is viewed by some as evidence of impropriety on the part of Japan, it would appear more accurate to describe it in retrospect as a sound business decision and furthermore one which could potentially have been available to the United States should we as a nation have chosen to embrace it. The U.S. was, it should be recalled, once in a position to enforce virtually any semiconductor market strategy it chose, having invented the technology, controlled the leading-edge research, dominated the related education, held the largest world market share, and consumed the majority of the product.

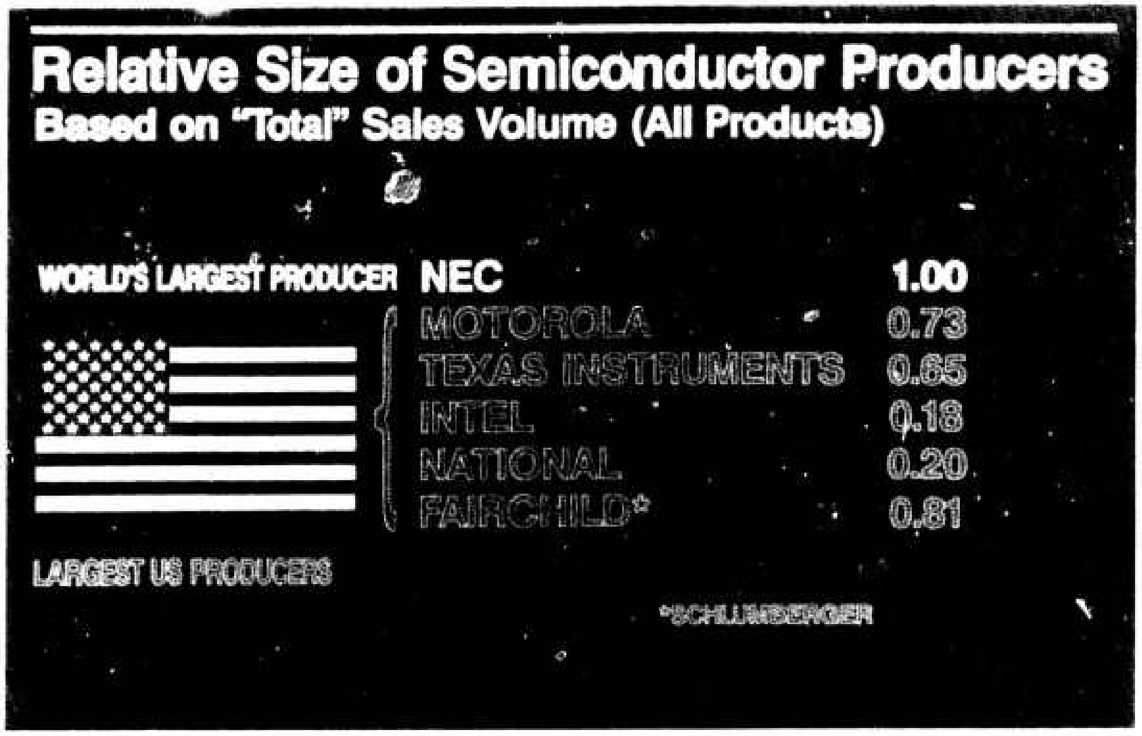


FIGURE 66.

The individual Japanese merchant semiconductor producers are generally larger than their U.S. counterpart firms. For example, NEC (Nippon Electric Company), the highest volume producer of semiconductors in the world, is between one-fourth larger and a factor of five larger than its major U.S. competitors. (The largest of the U.S. producers in terms of overall corporate size has recently been sold -- to a Japanese firm.)

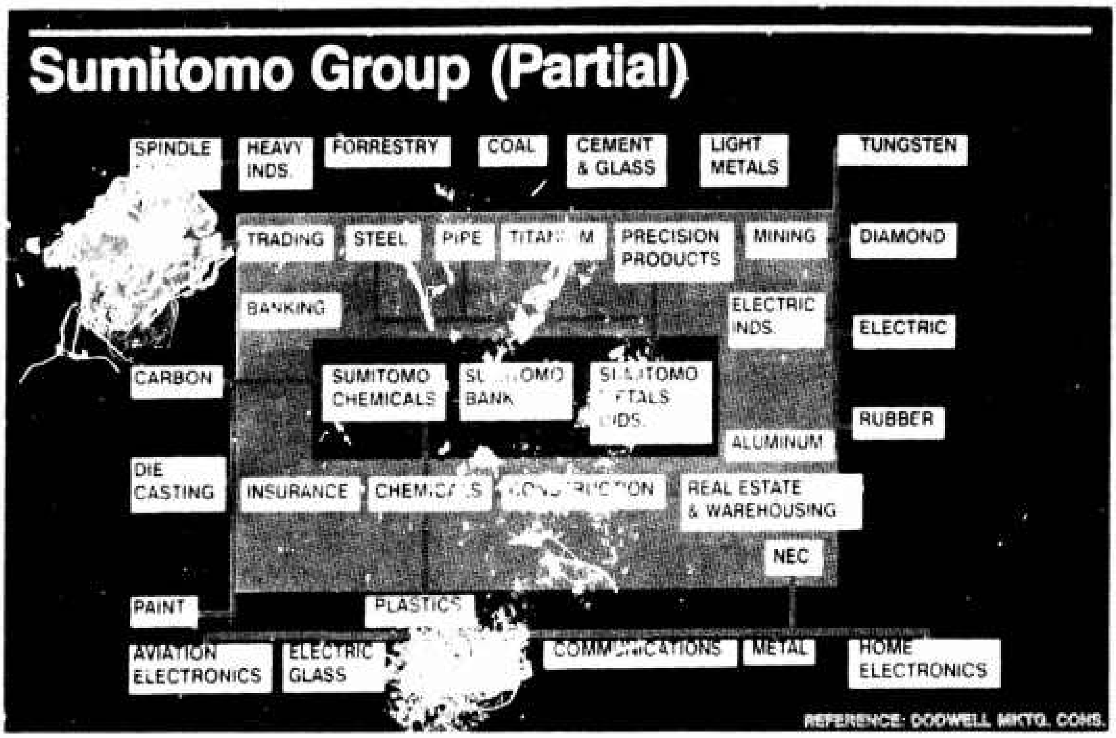


FIGURE 67.

As large as Japan's NEC would appear to be in comparison with many of its U.S. rivals in the semiconductor industry, it is seen to be only a small element of the Sumitomo Group, with which it is associated. This Group, one of a half-dozen of its type, provides virtually all ingredients needed to compete in virtually any market, centering on its own bank. By and large, Japanese semiconductor producers are members of such large industrial groupings. The importance of such a strategic structure is the ability to withstand and, in fact even exploit, transient reversals in the marketplace for a specific product such as semiconductors... relying on profits from other segments to buy time while capturing market position in the targeted industry.

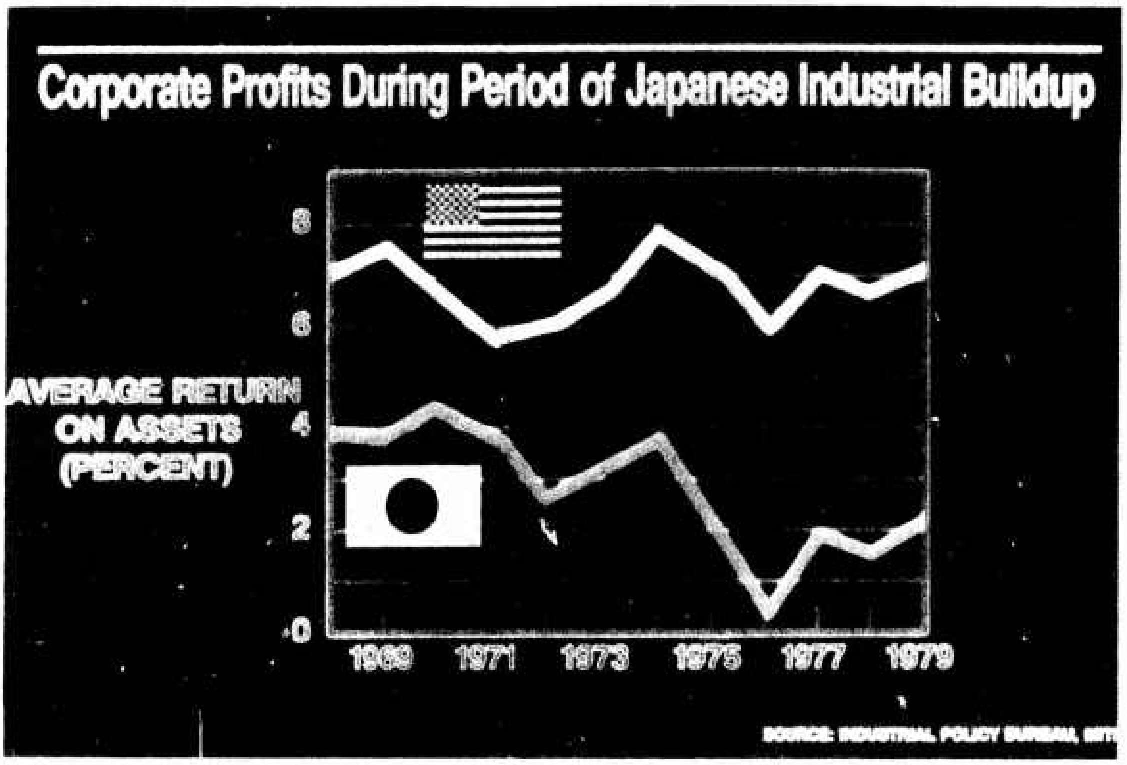


FIGURE 68.

The staying power of the large Japanese industrial entities is suggested by a comparison of the average return on assets of these firms with those of their U.S. counterparts during the era in which Japanese industry was making its major inroads on the word industrial market (the 1970's). It would seem unlikely that any U.S. firm could remain viable for a prolonged period producing a one to three percent return on assets -- as has been the case for much of Japanese industry.

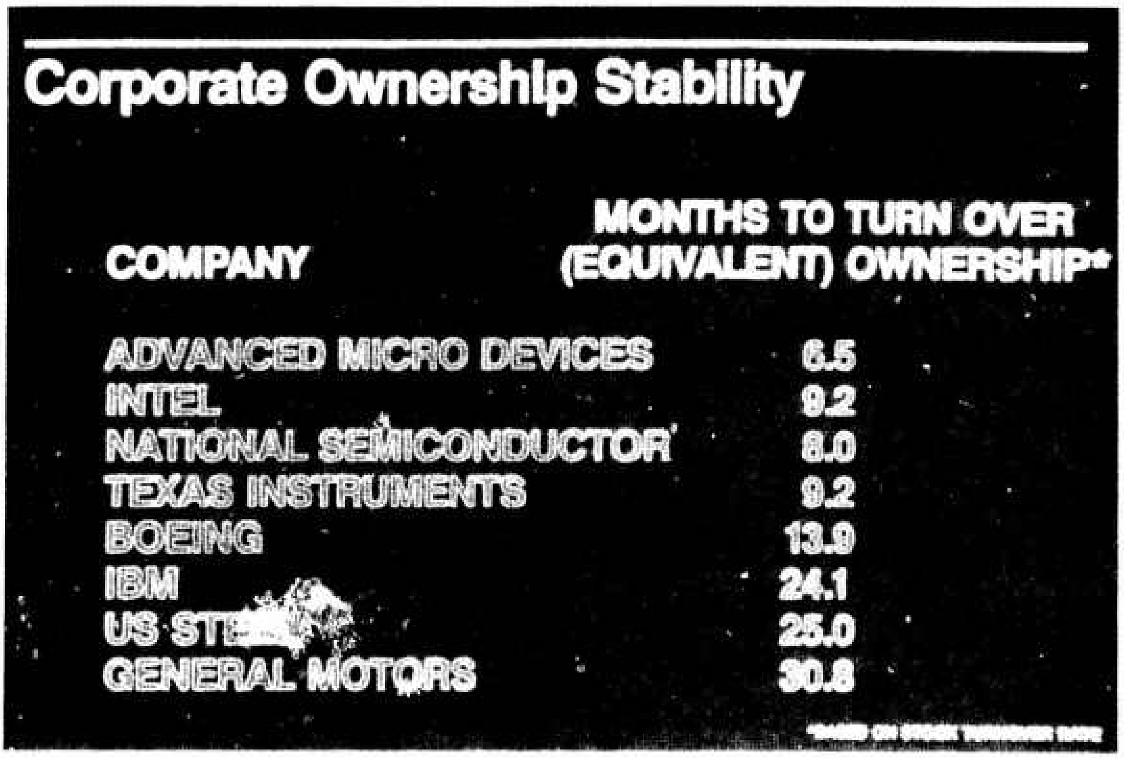


FIGURE 69.

The failure of the U.S. semiconductor industry to take a long term perspective in terms of pursuing strategic goals has often been cited as one cause of the industry's decline and there appears to be merit in this argument. It is noteworthy in this regard, however, that the average U.S. semiconductor manufacturer turns over its entire equivalent ownership (total number of shares divided by annual number of shares exchanged) every six to nine months. A project having a five-year payout is in effect heavily discounted by investors because it will be of direct benefit to owners seven to ten "generations" in the future. Thus, there is little motivation, in fact little tolerance, for management to seek truly long-term objectives. Rather, management finds itself under continued pressure to produce short-term results. This is in sharp contrast to the basic economic structure of Japanese industry.

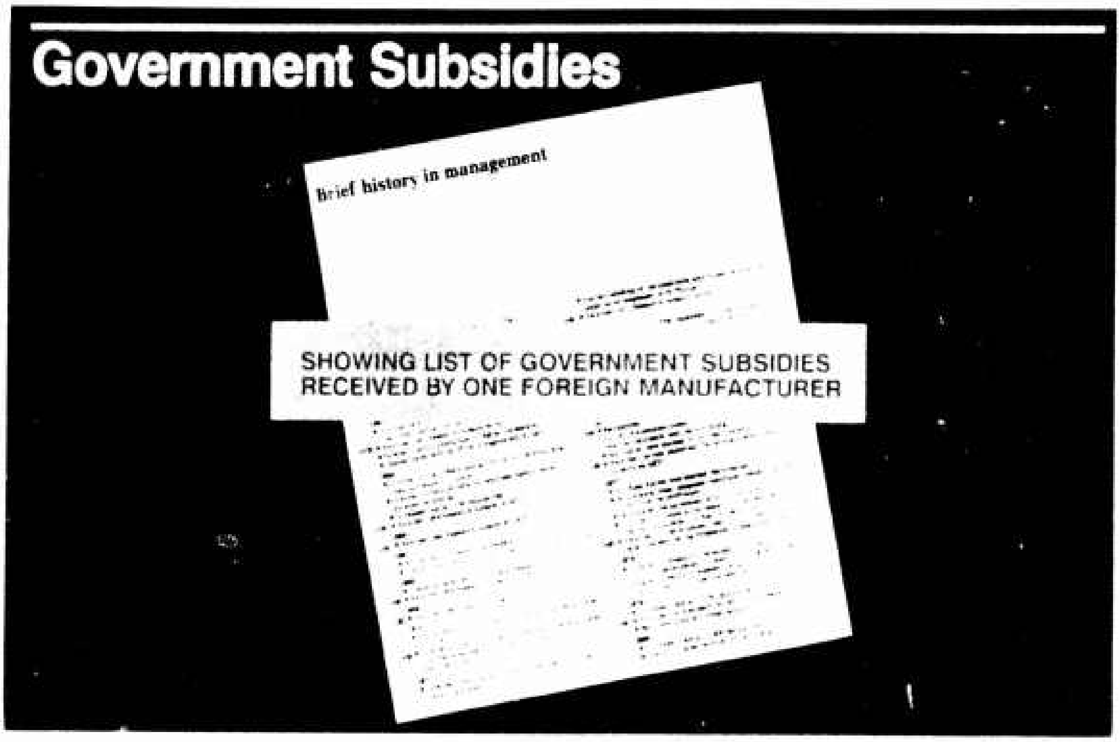


FIGURE 70.

When Japanese industrial and banking strengths are coupled with strong government backing in the form of subsidies (such as those listed in the above brochure of one Japanese semiconductor manufacturer), an extremely formidable competitor emerges. Although subsidies are often cited as a form of unfair competition -- at least as viewed by many U.S. industrial firms -- they are a fact of life in many world markets and are employed on occasion by the U.S. itself. For example, U.S. military support to the American semiconductor industry is often cited by Japan as a form of subsidy. The principal policy difference appears to be not in the existence of subsidies but rather in the fact that Japan has elected to focus its subsidies on emerging, leading edge industries; whereas the U.S. has to a considerable degree elected to subsidize sunset industries.

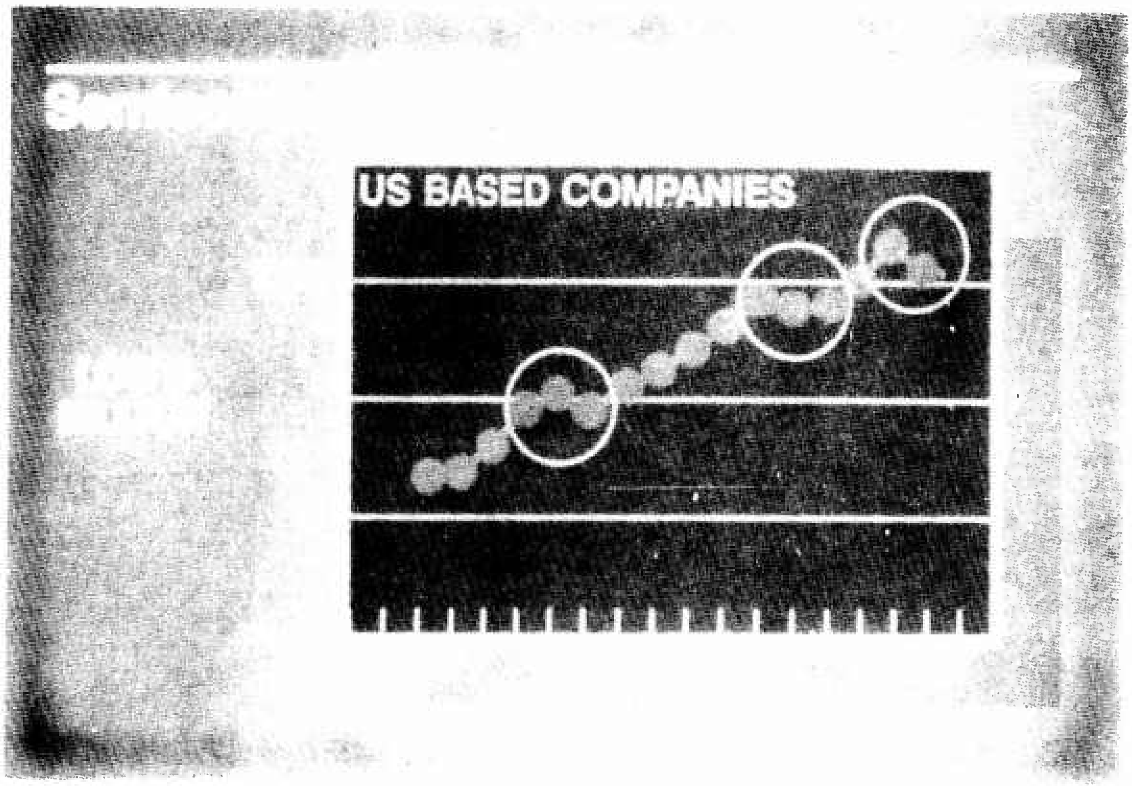


FIGURE 71.

Because of the staying power which has been made possible through the organizational structure and strategic focus of the Japanese semiconductor industry, reversals in the business cycle have had a markedly different impact on Japanese firms as compared with their U.S. counterparts. During each reversal, Japanese firms have sought to maintain market share, whereas their U.S. counterparts sought to maintain profitability (in order to assure survival and competitiveness for the capital needed to pursue succeeding generations of products). As the semiconductor industry emerged from each succeeding down-turn, more and more U.S. competitors were forced to drop out of the market altogether, whereas their Japanese counterparts tended to emerge with ever larger market shares upon which to base the next round of growth.

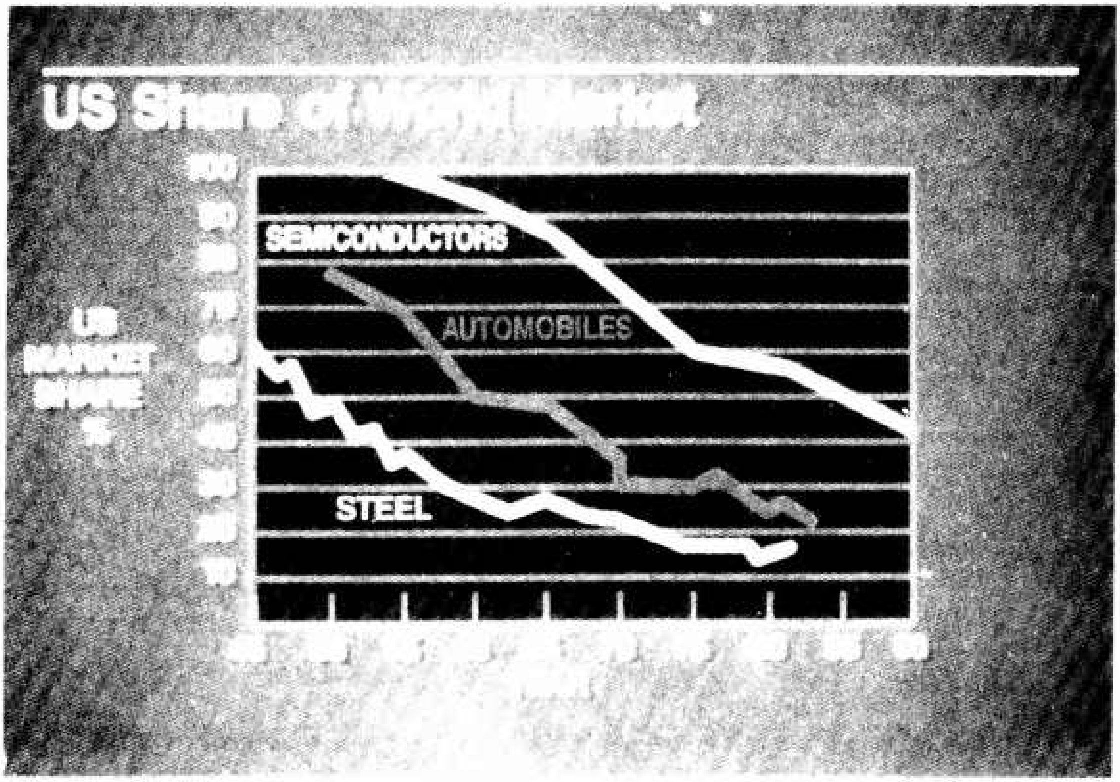


FIGURE 72.

A pattern has been established for the semiconductor industry which seems to have a growing parallel to that which has already been observed in such U.S. industries as steel and automobiles. The semiconductor industry is in its own regard not a major element of the U.S. manufacturing base. The concern, aside from national defense, resides in the fact that semiconductors are the essence of the computer and telecommunications industries which together form the basis for the information age. That is, the ability to dominate the semiconductor industry would appear to be a mere step along the strategic way for Japanese firms to dominate the world information market. This is perhaps the most ominous conclusion of the Task Force.

FIGURE 73.

The Task Force offers five principal recommendations, including one of predominant importance. In addition, it is observed with respect to assuring the availability of hardware in terms of mobilization that it will be necessary for Defense Department program offices to maintain records of hardware origin (with full traceability) and either stockpile parts or provide in advance for alternate domestic sources on a suitable time scale.

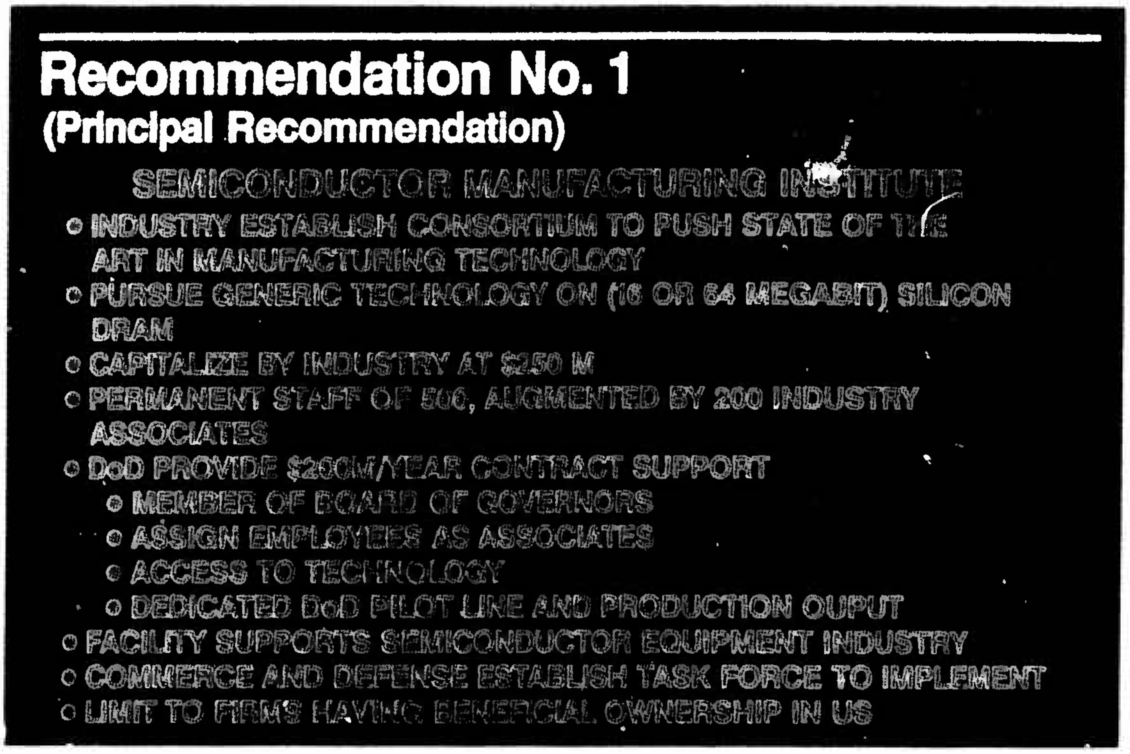


FIGURE 74.

The principal and most crucial recommendation of the Task Force is that an Institute be established by a consortium of U.S. firms, somewhat along the lines already practiced in Japan, to jointly advance the state-of-the-art in generic semiconductor manufacturing technology. An appropriate objective would be the development of the manufacturing technology needed for the 64 megabit DRAM. The Institute would be staffed with a highly selective permanent staff augmented by key personnel from the participating organizations. The purpose of the latter would be to assist in the technology transfer process. Representatives of academia would have access to the facilities subject to approval by the Institute's Board of Governors and equipment manufacturers would be able to use it for prototyping new products. Such a consortium would be capitalized by its industrial members and the Department of Defense would provide continued annual contract support in the amount of about $200M per year in exchange for access to the technology generated and a portion of the product output. It may prove desirable for the Department of Defense to augment the above capitalization in order to provide a dedicated flexible manufacturing line purely for defense purposes. The cost of this latter facility would be approximately an additional $100 million.

Recommendation No. 2

UNIVERSITY RESEARCH

- FUND EIGHT UNIVERSITY CENTERS OF EXECELLENCE ($50M/YEAR TOTAL)
  - ELECTRONIC MATERIALS
  - ELECTRON DEVICES
  - RADIATION HARDENING
  - MANUFACTURING TECHNOLOGIES
  - PACKAGING TECHNIQUES
  - TESTING TECHNOLOGY
  - DESIGN TECHNOLOGY
  - ETC.
- MANAGE THROUGH DARPA OR USDRE VHSIC OFFICE
- FOCUS ON MANUFACTURING-RELATED SCIENCE AND EDUCATION OF HIGHLY QUALIFIED STUDENTS

FIGURE 75.

A relatively modest investment in Centers of Excellence at perhaps eight universities will have major payoff in terms of assuring the competitiveness of the United States in critical advanced semiconductor technologies.

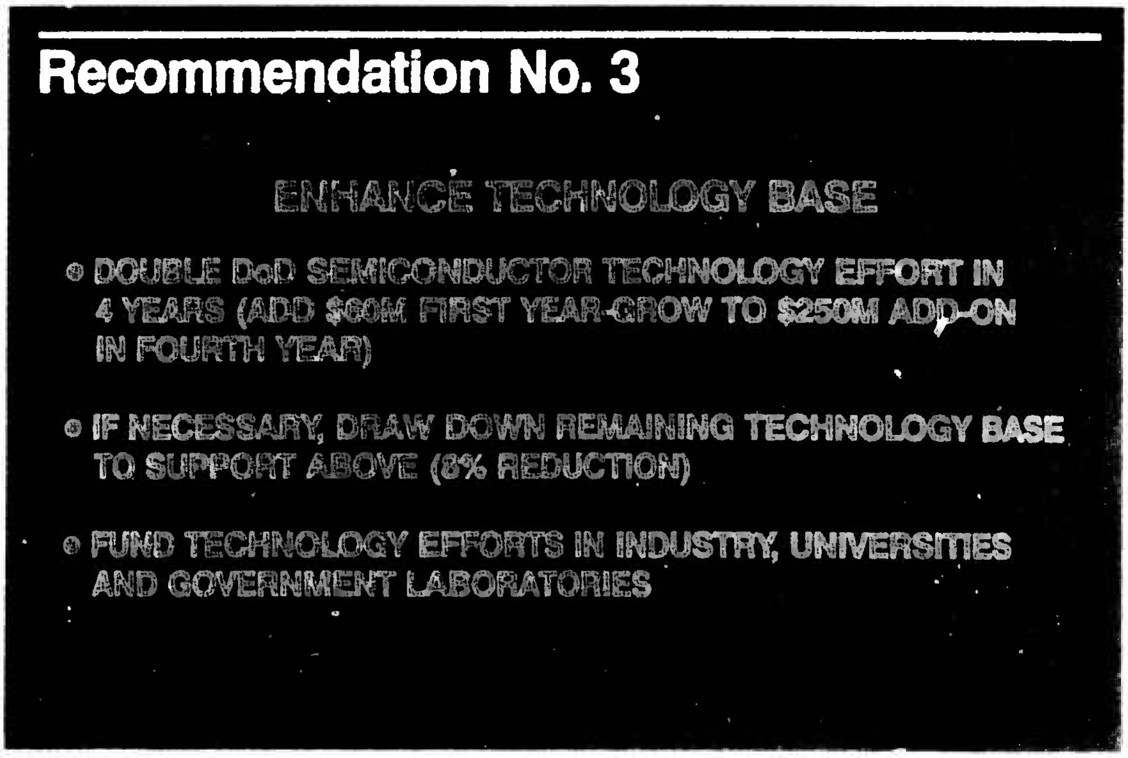


FIGURE 76.

If the U.S. is to have the benefit of the latest developments in semiconductor devices for national defense, it will be necessary for the Department of Defense to carry a larger share of the financial burden in terms of advancing the underpinning technology. A doubling of the Department's expenditures for this purpose during the next four years appears both warranted and feasible. Even if no additional funds were to become available during this period with which to support the overall defense technology base, a shift into semiconductor research and technology development of about eight percent of the currently available funds in this category would enable the above-mentioned doubling in support. Although there are good economic reasons on behalf of the nation's economy as a whole to make further investments in a strong semiconductor industry, the recommended spending is justified purely on a military basis.

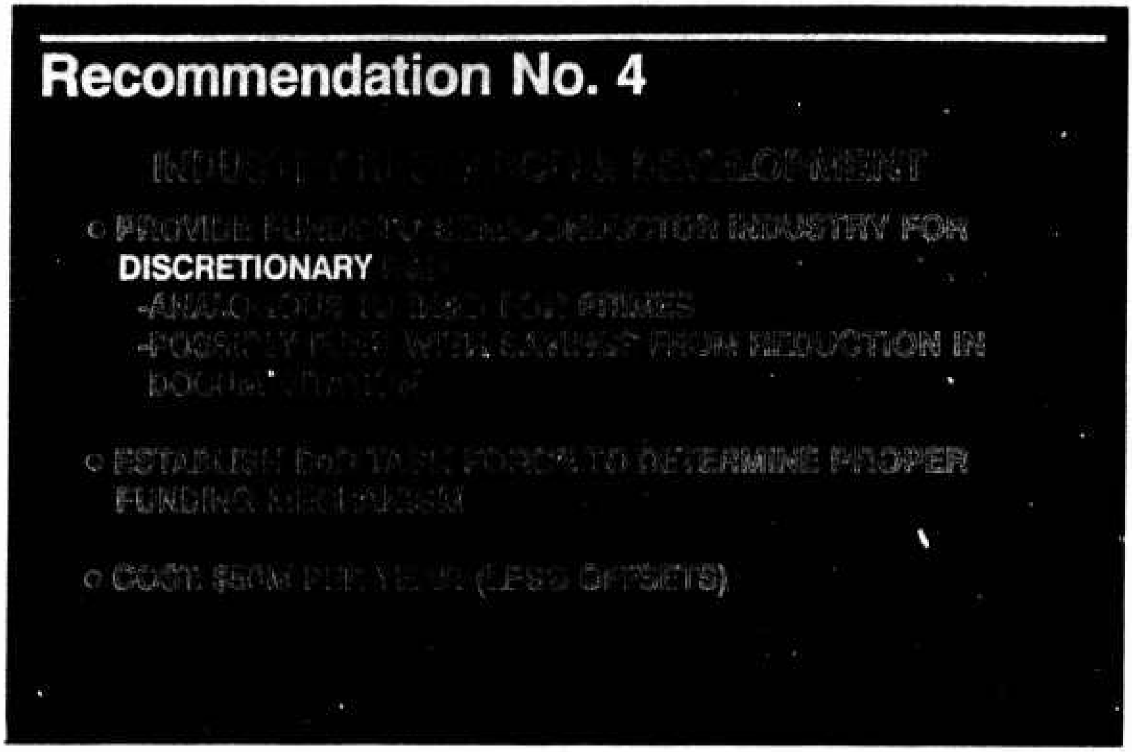


FIGURE 77.

The U.S. merchant semiconductor producers who seek to satisfy defense requirements have no direct access to funds such as Independent Research and Development which is life-sustaining to the technology produced by the Defense Department's prime contractors. The DoD should establish a mechanism to provide funds to the merchant semiconductor producers who supply defense needs in order to support discretionary research and development which is related to defense.

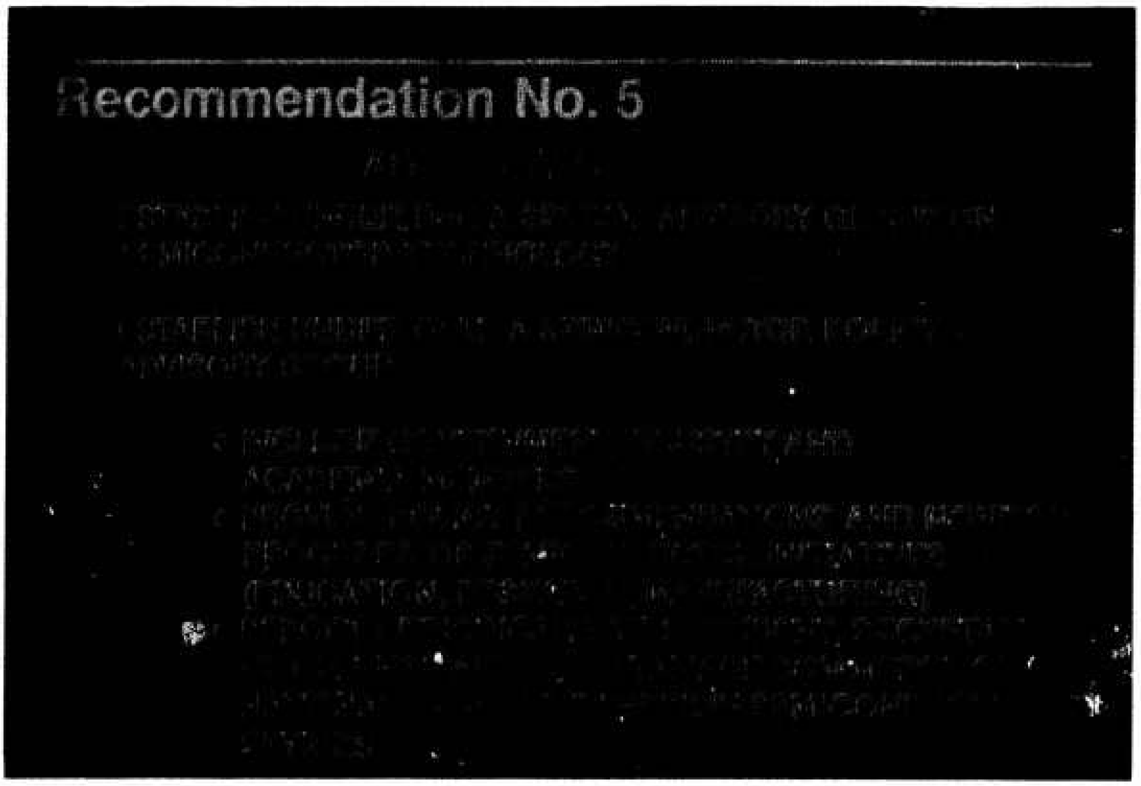


FIGURE 78.

A group should be established by the Department of Defense to oversee the implementation of the recommendations noted herein. In addition, the Office of Science and Technology Policy should establish a semiconductor policy board to provide a forum for government, industry and academia to exchange information to assure the competitiveness of the U.S. semiconductor industry insofar as it affects both national defense and the overall health of the U.S. economy.

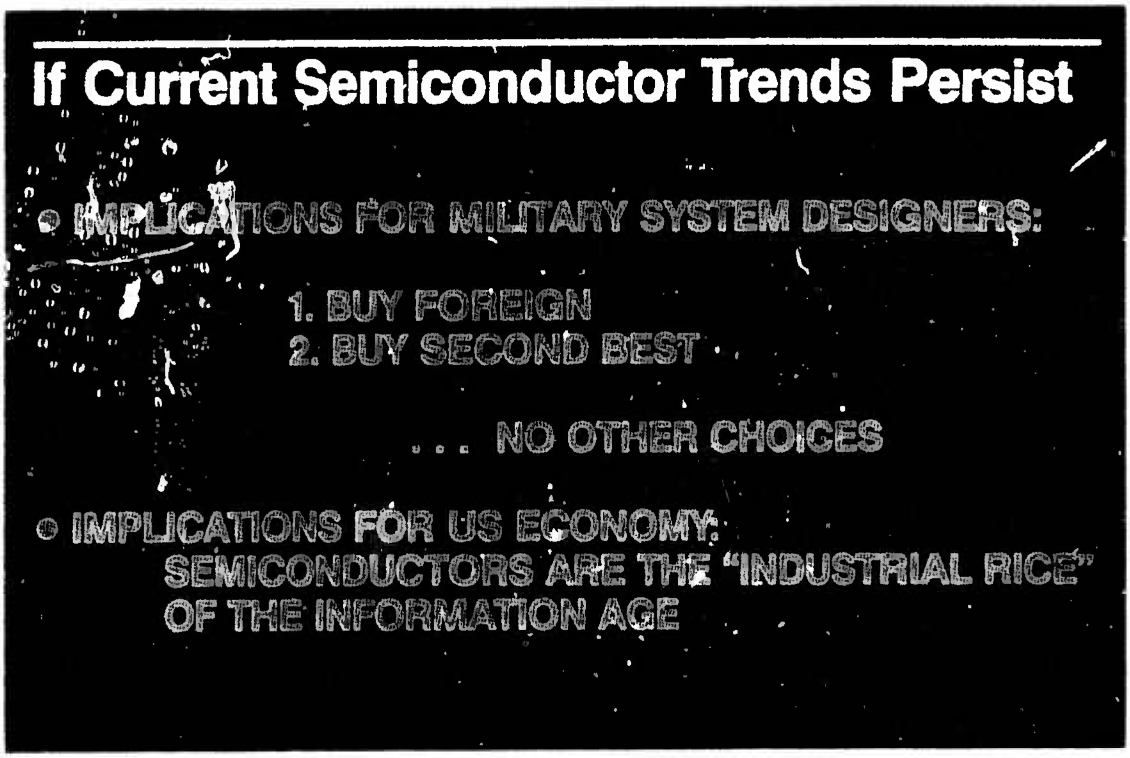


FIGURE 79.

In summary, if the established trend in the critically important semiconductor manufacturing technologies is allowed to persist, it appears likely that in the 1990's U.S. military system designers will be faced with a choice from but two alternatives. The first of these alternatives is to buy foreign semiconductors and accept the implications of technological and materiel dependence attendant therewith. The second is to settle for "second best" semiconductor devices and the systems they support. In terms of implications for the overall U.S. economy, semiconductors truly are "the industrial rice" of the information age and, as the information industry becomes a growing element of the world economy, it would appear critically important for the U.S. to regain and maintain a strong competitive position in this field.

FIGURE 80.

Japan is a strong and essential ally of the United States. Nonetheless, its economic interests occasionally differ from those of the U.S. ... much as the interests of the U.S. have on occasion differed with respect to those of our European allies. Because of this, it would appear unwise for the U.S., a nation with worldwide interests and obligations, to accept any policy which entails sole source dependence upon foreign countries for critical military hardware or technology.

SUPPLEMENTAL BRIEFING CHARTS

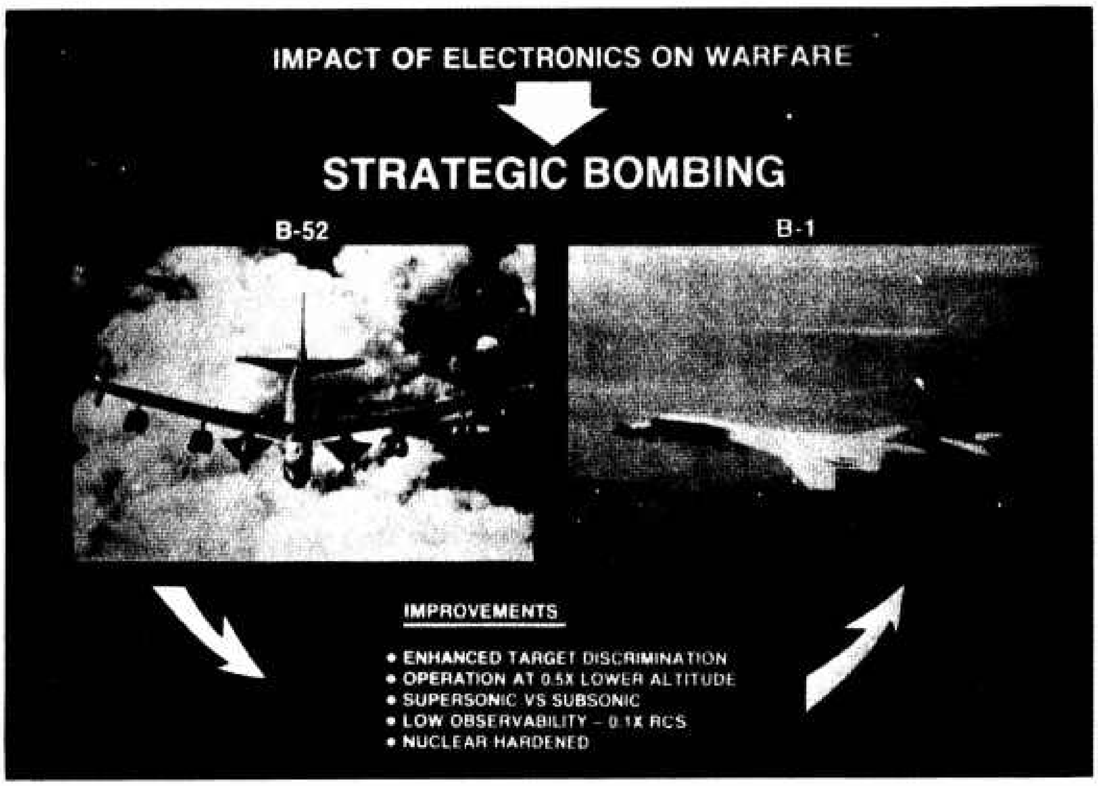


FIGURE A.

Modern bomb/navigation systems permit precision location of aircraft and target position as well as supporting flight at extremely low altitudes. These capabilities have been achievable in substantial part through advancements in solid state electronic technology.

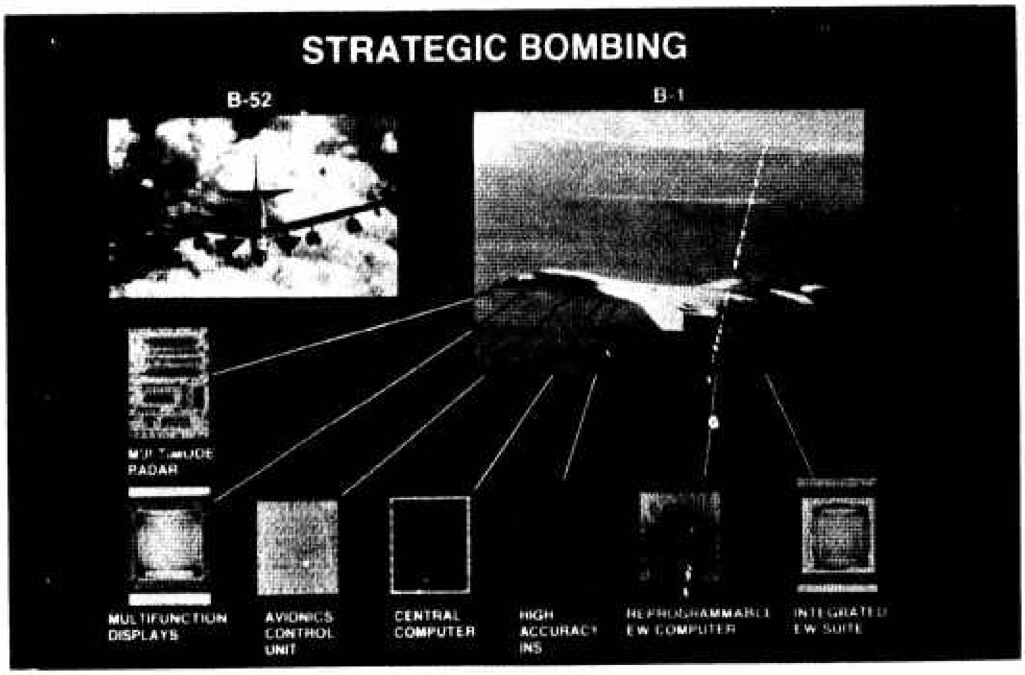


FIGURE B.

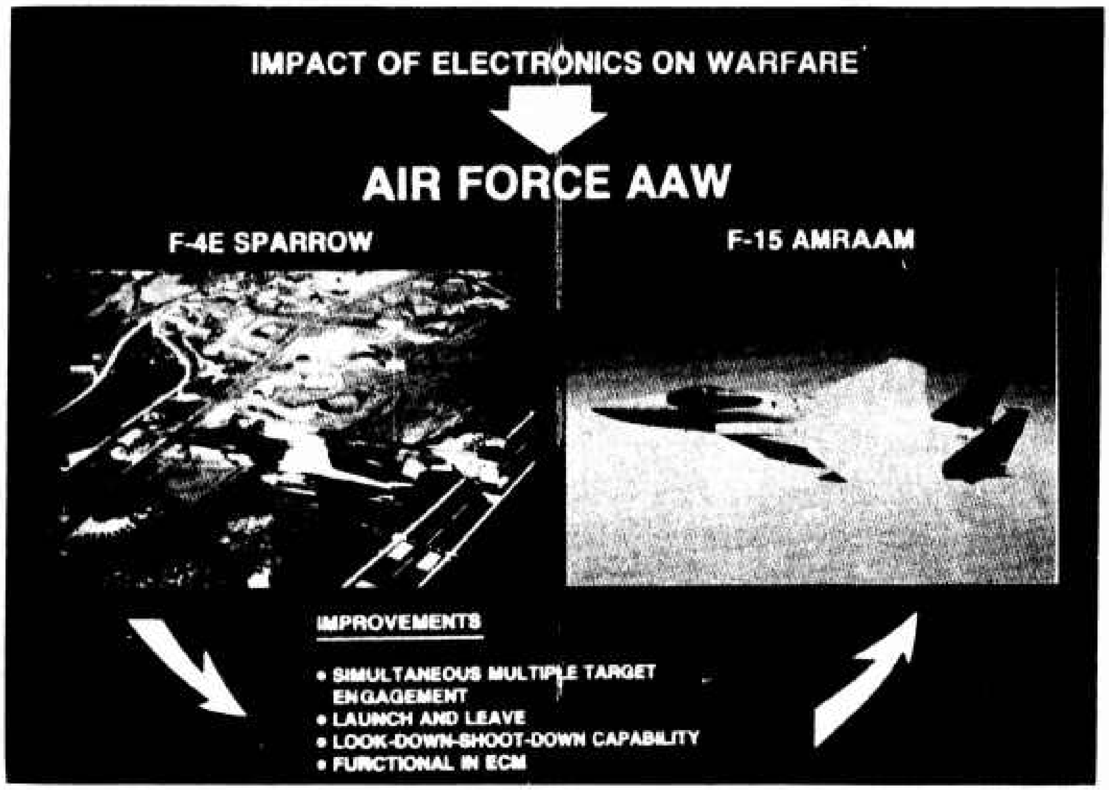


FIGURE C.

Modern tactical aircraft provide the capability to engage several highly maneuvering aerial targets simultaneously in a severe electronic countermeasures environment and to do so even against very low flying threats.

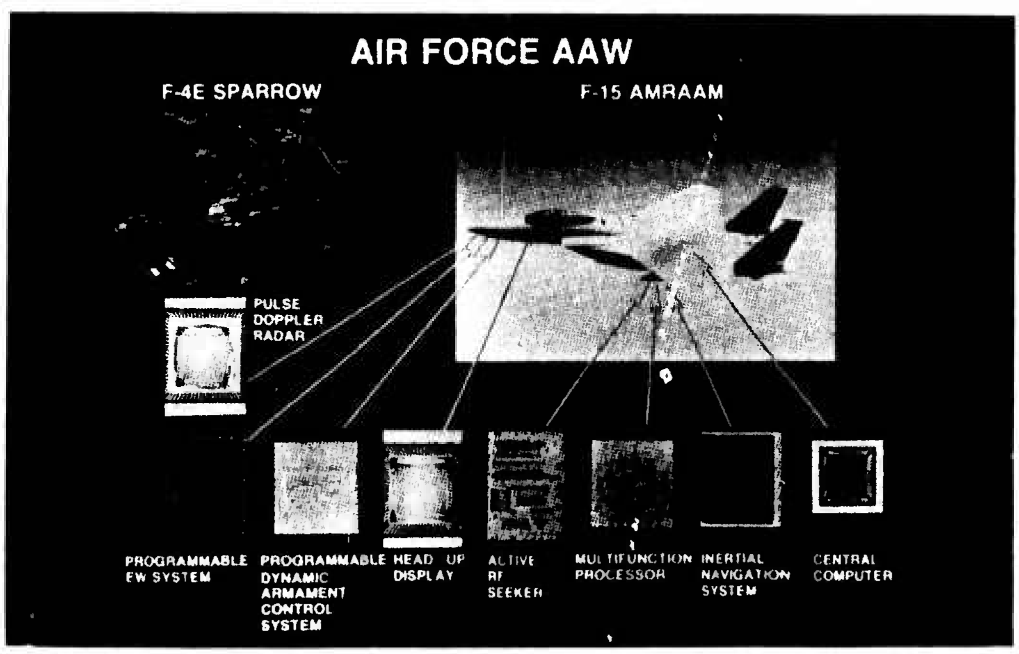


FIGURE D.

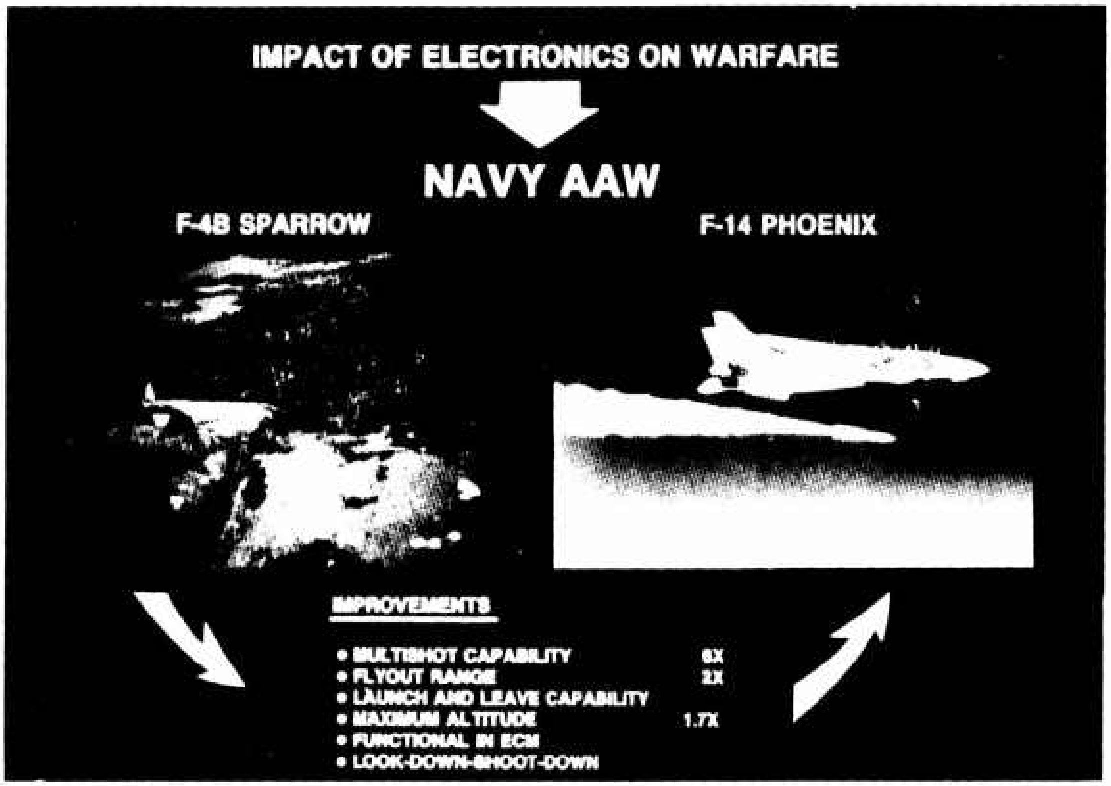


FIGURE E.

Modern air-to-air missiles and airborne fire control radars developed for Navy anti-air warfare missions provide the capability to engage six targets simultaneously at extended ranges at all threat altitudes and in an intense electronic warfare environment.

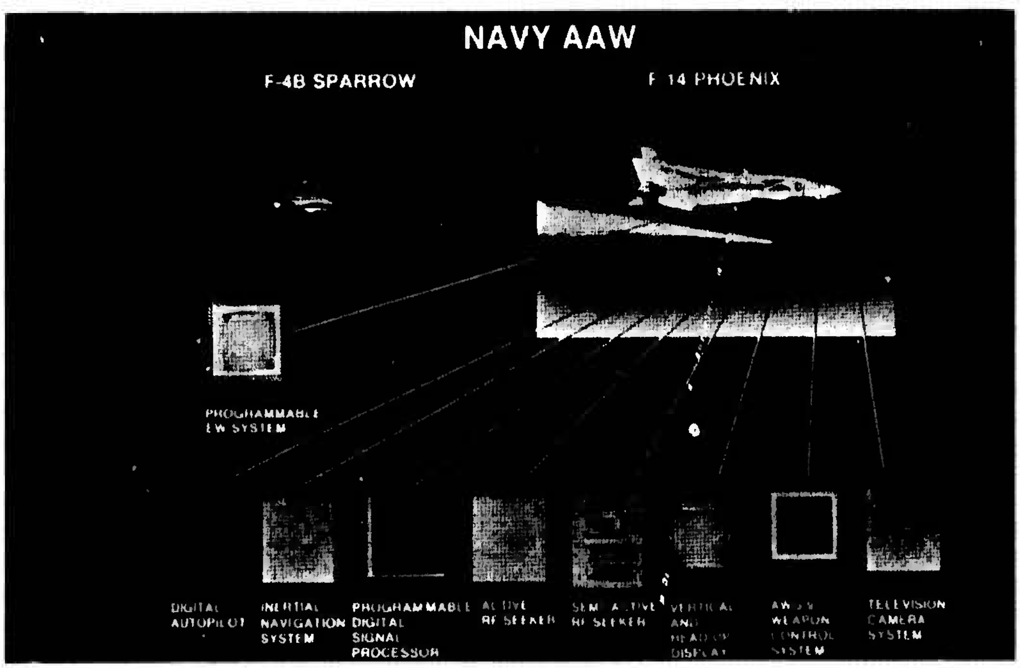


FIGURE F.

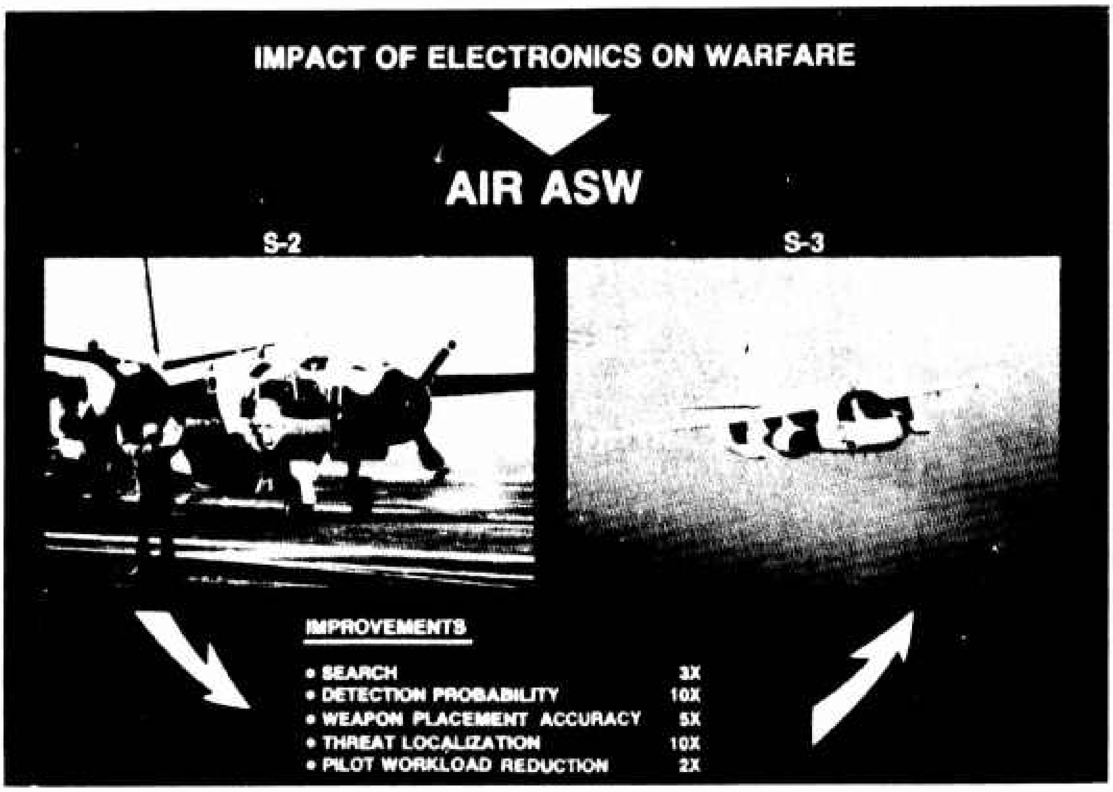


FIGURE G.

Anti-submarine forces have achieved major advancements during the past decade in such areas as search volume, detection probability and weapon placement accuracy.

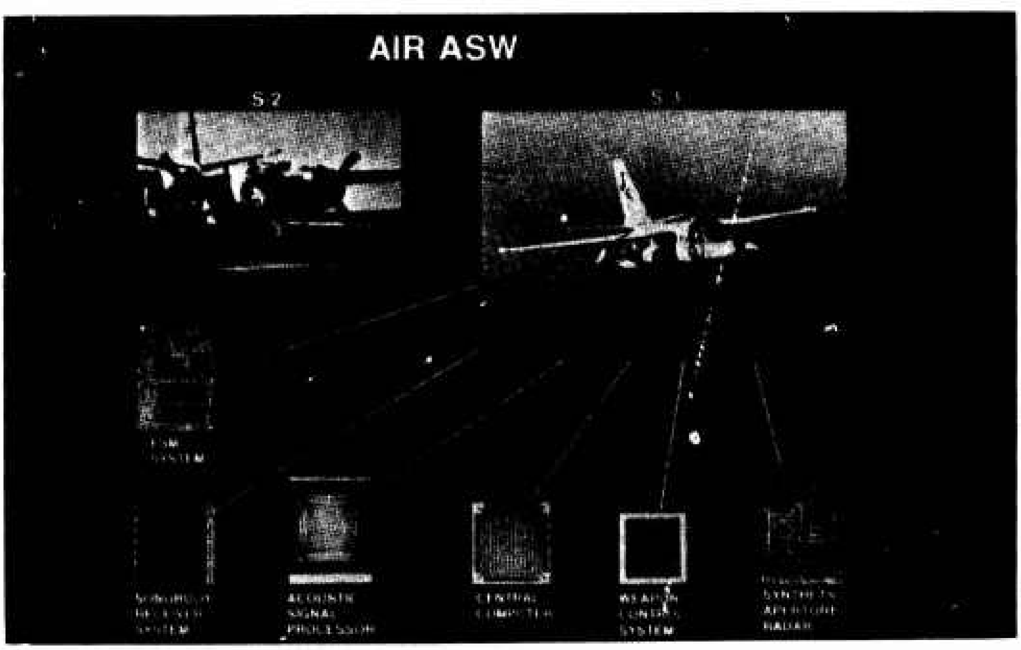


FIGURE H.

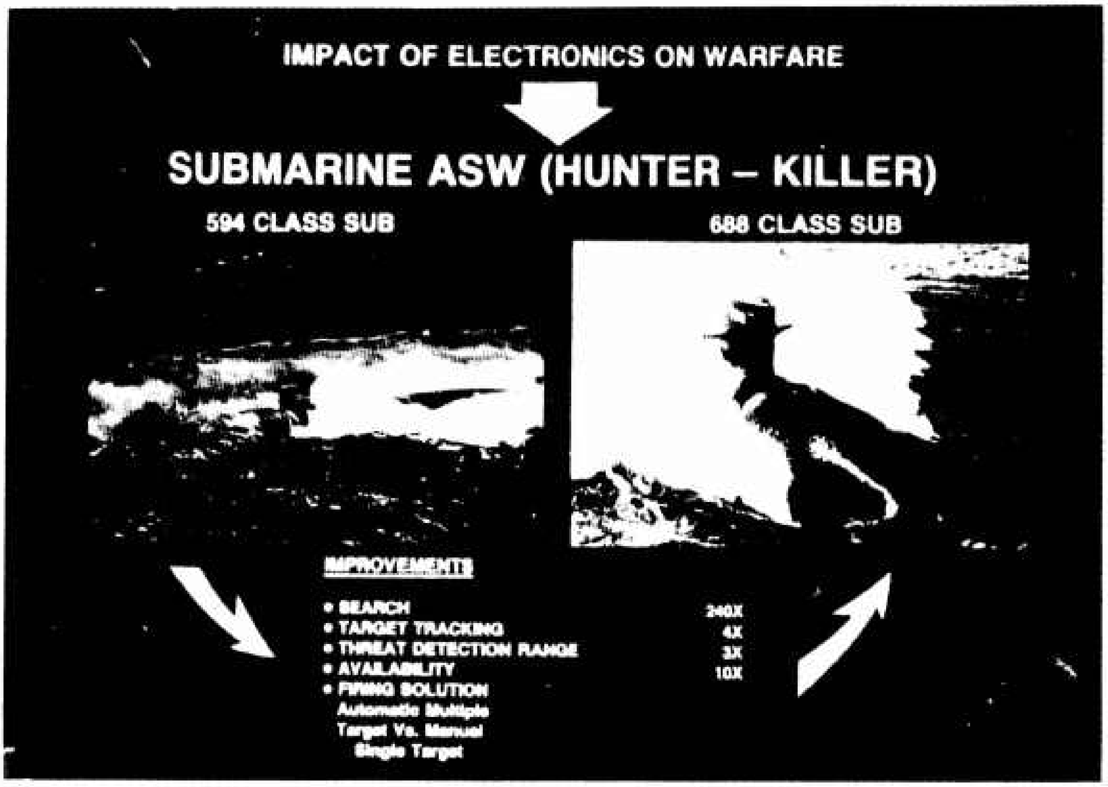


FIGURE I.

Significant advances have been made in submarine operations in recent years with the advent of modern search and tracking systems, including information processing systems, as well as advanced torpedo technology.

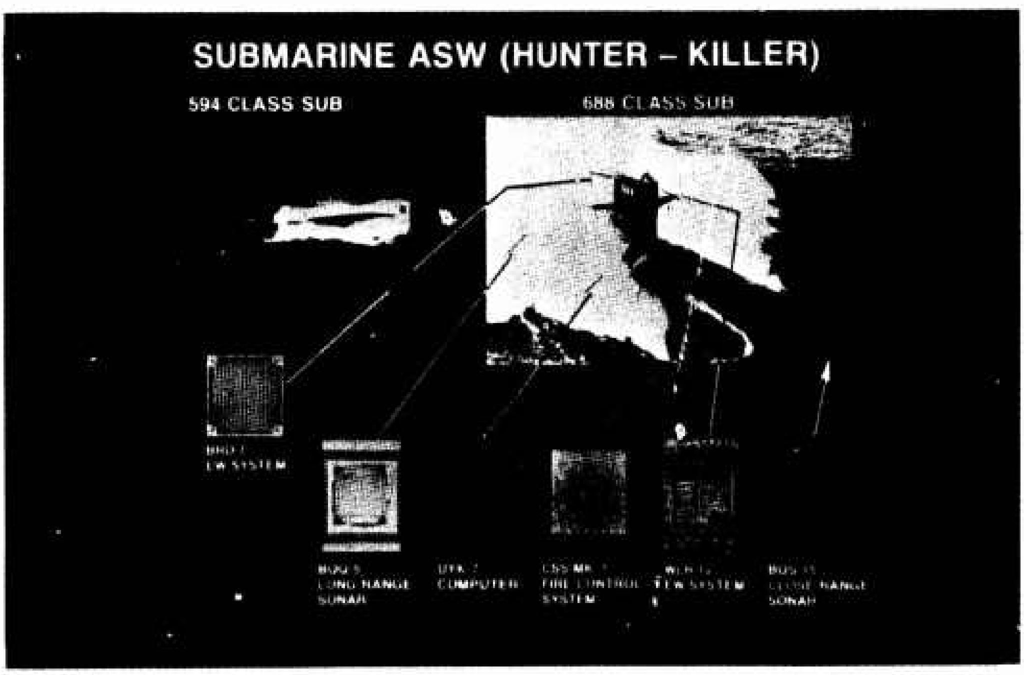


FIGURE J.

SECTION III.

TERMS OF REFERENCE

THE UNDER SECRETARY OF DEFENSE

WASHINGTON, DC 20301-3010

RESEARCH AND ENGINEERING

3 DEC 1985

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: DSB Task Force on Semiconductor Dependency

You are requested to organize a Defense Science Board Task Force to address the impact of possible dependency of the U.S. military on foreign sources for semiconductor devices.

To an increasing extent, semiconductor devices are being employed in U.S. military systems of virtually all types. Applications include missiles, aircraft, spacecraft, command and control systems, fire control, etc. In the past, the U.S. has possessed a burgeoning domestic semiconductor industry to serve as a source of these critical components for military systems. Recent events in the semiconductor industry, however, caused in part by increasing foreign competition, appear to threaten the long-term viability of major segments of the U.S. industrial base in this area. Whether the domestic semiconductor industry can (and should) continue to be the principal supplier of such electronics to the Department of Defense and to its systems contractors is a matter of some importance as well as uncertainty.

Accordingly, the Defense Science Board Task Force on Semiconductors is requested to conduct an assessment addressing, but not limited to, the following questions:

1. To what degree is U.S. military capability dependent upon the use of semiconductor devices insofar as systems in production or previously deployed are concerned?

2. To what extent are domestic sources currently available to supply the semiconductor devices incorporated in operational and production military systems?

3. What is the projected trend for the availability in peacetime, mobilization, and wartime of a domestic supply of semiconductor devices for military applications?

4. Is it essential that domestic fabrication sources be available for semiconductor devices to be used in U.S. military systems? Must these sources be in operation during peacetime? Is stockpiling a practicable alternative?

5. What is the projected trend for the U.S. semiconductor industry with respect to its ability to stay at the leading edge of the semiconductor device state of the art? What requirements are imposed by the demand to advance or stay abreast of the state of the art in semiconductor devices?

6. What, if any, specific actions should be undertaken to assure an adequate supply of such devices and semiconductor technology for use in defense systems?

Although the semiconductor memory market is a principle area of intended focus, the study should include whatever breadth within the semiconductor field that is deemed appropriate by the Task Force itself.

Administrative Approach

The Semiconductor Dependency Task Force is sponsored by Deputy Under Secretary of Defense for Research and Engineering (Research and Advanced Technology). Mr. Norman R. Augustine, Defense Science Board Member, has agreed to Chair the Task Force. The Executive Secretary will be Mr. Egbert D. Maynard and the DSB staff representative will be Colonel Donald W. Derrah, USA. It is requested that the study be initiated at the earliest possible time. In order to assure that input is received from organizations intimately involved in the day-to-day semiconductor production field, it is requested that an industrial consultation group be established to augment the Task Force itself. It is considered that the subject matter of this study does not involve "particular matters" within the meaning of Section 208 of Title 18, U.S. Code.

Donald A. Hicks

Donald A. Hicks

SECTION IV.

TASK FORCE MEMBERSHIP

TASK FORCE MEMBERSHIP

CHAIRMAN

Mr. Norman R. Augustine	President - Martin Marietta Corporation Former Chairman, Defense Science Board Former Undersecretary of Army Former President, American Institute of Aeronautics and Astronautics Chairman, NASA Space Systems and Technology Advisory Committee Member, National Academy of Engineering

TASK FORCE MEMBERS

Dr. Erich Bloch	Director, National Science Foundation Former Vice President Technical Personnel Development, IBM Former Engineering Manager, IBM Stretch Supercomputer Former Vice President, IBM Data System Division Former General Manager of East Fishkill Facility, IBM Member, National Academy of Engineering
Dr. Robert M. Burger	Staff Vice President, Semiconductor Research Corporation Chief Scientist, Research Triangle Institute Editor and Author of Several Books on Integrated Circuits
Dr. Malcolm R. Currie	President, Delco Electronics Corporation and Executive Vice President, Hughes Aircraft Company Member Defense Science Board PhD, University of California at Berkeley Former Vice President Research and Development, Beckman Instruments Former Undersecretary of Defense, Research and Engineering Member, National Academy of Engineering
Dr. Richard D. DeLauer	President, Orion Group Ltd. Former Undersecretary of Defense, Research and Engineering Fellow of American Institute of Aeronautics & Astronautics Former Vice President, TRW Member National Academy of Engineering

TASK FORCE MEMBERS (continued)

Mr. J S. Kilby	Inventory of Integrated Circuit Texas Instruments 1958-1970 (Semiconductor R&D) Chairman, Advisory Group on Electron Devices National Inventors Hall of Fame Member, National Academy of Engineering
Gen. Robert T. Marsh (Ret.)	Consultant, Aerospace Industry Director, Morton Thiokol, Inc. Trustee, Mitre Corporation Advisor, Software Engineering Institute (Carnegie-Mellon) Former Commander Air Force Systems Command Former Commander Electronics Systems Division, USAF
Dr. James D. Meindl	Vice President for Academic Affairs and Provost, Rensselaer Polytechnic Institute Former John M. Fluke Professor of E.E., Stanford University Director, Center of Integrated Systems, Stanford University 1980 (IEEE) J.J. Ebers Award for Outstanding Contributions to Electron Devices Former Director, Integrated Electronics Division, Electronics Command, U.S. Army PhD Electronic Engineering, Carnegie-Mellon University Member, National Academy of Engineering
Dr. Walter E. Morrow	Director, Lincoln Laboratory, Massachusetts Institute of Technology Chief of Naval Operations Exec. Panel Member Defense Communications Agency Scientific Advisory Group USIA Voice of America Radio Engineering Advisory Committee Member, National Academy of Engineering
Mr. Lionel Olmer	Former Undersecretary of Commerce for International Trade Former Director International Programs, Motorola Corp. Former Executive Secretary, The President's Foreign Intelligence Advisory Board
Mr. Larry Sumney	President, Semiconductor Research Corporation Former Manager Tri-Service Charge Coupled Device Program Former Staff Specialist Electronic Devices and Integrated Circuit Technology, OUSDRE Former Director, VHSIC Program, OUSDRE Senior Member of IEEE

SPECIAL DSB ADVISOR

Dr. Solomon J. Buchsbaum	Executive Vice President, Customer Systems, Bell Laboratories Former Chairman, Defense Science Board Chairman, White House Science Council Former Vice President, Sandia Laboratories Former Chairman, Energy Research Advisory Board, DOE Member, National Academy of Engineering

TASK FORCE ADVISORS

Mr. William Gianopulos	Director of Manassas, Va. IBM Laboratory, Federal Systems Division, and Manager, IBM VHSIC and VHSIC Insertion Programs Former Director Very Large Scale Integrated Systems, IBM Former IBM Group Technical Staff, Technology Insertion Former Laboratory Director, Kingston, New York System Communications Division, IBM Former Team Manager for First IBM Design and Production of Large Scale Integration Microprocessor
Dr. George H. Heilmeier	Senior Vice President and Chief Technical Officer, Texas Instruments Member, Defense Science Board Former Director, Defense Advanced Projects Agency PhD, Solid State Electronics, Princeton University IEEE David Sarnoff Award (Electronics) IEEE Philips Award (R&D Management) 1986 IEEE Founders Medal (Outstanding Leadership in Semiconductor R&D) Member, National Academy of Engineering
Dr. William G. Howard	Senior Vice President and Director of Research and Development, Motorola, Inc. Former Assistant Professor of Electrical Engineering and Computer Sciences, University of California, Berkeley Chairman, Working Group B of DOD Advisory Group on Electronic Devices Former Chairman, Department of Commerce Semiconductor and Technology Advisory Committee Member, National Academy of Engineering

TASK FORCE ADVISORS (continued)

Adm. Bobby R. Inman (Ret.)	President and Chief Executive Officer, MCC Corporation Member, Defense Science Board Former Deputy Director, Central Intelligence Agency Former Director, National Security Agency Former Vice Director (Plans, Operations, and Support), Defense Intelligence Agency
Dr. Robert N. Noyce	Vice Chairman of the Board, Intel Corporation BS in Science, Grinnell College, Ohio PhD, Massachusetts Institute of Technology Recipient of the National Medal of Science Member, National Academy of Engineering
Mr. Michael Thompson	Executive Director, Integrated Circuit Processing Division, AT&T Bell Laboratories Former Director of Development Laboratories Engaged in Digital Transmission and Switching Systems, Image and Signal Processing

EXECUTIVE SECRETARY

Mr. E.D. Maynard, Jr.	Director, VHSIC/Electronic Devices, OUSDRE/R&AT Former Electronics Engineer Program Manager, Naval Oceanographic Systems Center Former Electronics Engineer, Naval Electronic Laboratory Center Former Supervisory Electronics Engineer, U.S. Air Force Avionics Laboratory Former Electronics Engineer to Research and Development Electronics Exploration Group, Wright Patterson Air Force Base

DSB STAFF REPRESENTATIVE

Col. Donald R. Fang	Army Military Assistant for Defense Science Board, Office of the Secretary of Defense

DOD REPRESENTATIVES

Mr. Richard E. Donnelly	Director, Industrial Resources, ASDA&L Former Staff Member, HQ, USAF for Industrial Research Management Presidential Meritorious Executive Award
Dr. Lawrence Gray	Director, Solid State Electronics Division, Naval Ocean Systems Center Member, Joint Logistics Commander's Joint Technical Working Group on Microcircuit Obsolescence Member, Navy Microcircuit Obsolescence Management Committee Former Director, Navy Microelectronics Laboratory
Dr. William T. Marquitz	Director, National Intelligence Systems, OASD/C^3I Former Special Assistant, Office of Development and Engineering, DD/S&T, Central Intelligence Agency, Microelectronics and Electro-Optics Systems and Components Former Program Manager, Information Processing Techniques Office, DARPA, Optical Disk Recorder, CCD Signal Processors PhD, Electrical Engineering, Michigan State University
Lt. Gen. Emmett Paige	Commander, U.S. Army Information Systems Command Former Commander U.S. Army Electronics Research and Development Command Former Commander of U.S. Army Communications, Research and Development Command
Mr. David S. Tarbell	Director of International Economics and Energy Affairs, OASD/ISA Former Staff Assistant, National Security Council Masters Degree, Wharton, University of Pennsylvania
Dr. Robert W. Thomas	Chief, Product Evaluation Branch, Rome Air Development Center Former Program Manager, Rome Air Development Center PhD, Solid State Science, Syracuse University

DOD REPRESENTATIVES (continued)

Dr. Clarence G. Thornton	Director, United States Army Electronic and Technical Devices Laboratory Former Chief, Semiconductor Devices Division (ETDL) Former Director, Research and Engineering, Philco Ford IEEE Fellow
Mr. Edmund J. Westcott	Technical Director, Deputy Chief of Staff for Product Assurance and Acquisition Logistics Systems Commmand, USAF Former Technical Director Reliability and Compatibility Division, Rome Air Development Center MSEE, Drexel University

TECHNICAL SUPPORT

Mr. Harold E. Bertrand	Senior Consultant, Science and Technology Div., Institute for Defense Analyses President, Potomac Consulting Group, Inc. Former Vice President, J. Watson NOAH, Inc. Former Research Fellow, Logistics Management Institute Former Associate Director, SRI
Dr. Jeffrey Frey	Professor of Electrical Engineering, Cornell University Former Visiting Professor, University of Tokyo Consultant to General Electric/Japan Former Manager, Device Physics and Advance Lithography, Signetics Corp. Former Director, Semiconductor Research Corp., Center of Excellence in Microstructures
Dr. Richard H. Van Atta	Director, Technology Security Policy, Science and Technology Division, Institute for Defense Analyses Former Program Manager, C^3I Programs, BETAC Corporation Former Project Manager, Defense Studies, MATHTECH, Inc. Former Assistant Professor, School of International Service, The American University